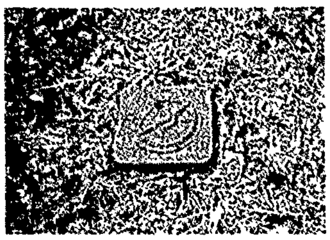
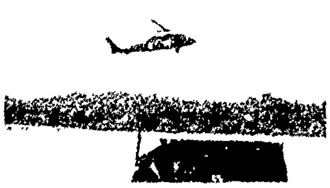
US Army Corps of Engineers





TECHNICAL REPORT EL-91-5

SITE CHARACTERIZATION FOR REMOTE MINEFIELD DETECTION SCANNER (REMIDS) SYSTEM DATA ACQUISITION

by

Katherine S. Long, Kenneth G. Hall

Environmental Laboratory

DEPARTMENT OF THE ARMY
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April 1991
Final Report

Approved for Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Belvoir Research, Development and Engineering Center
Fort Belvoir, Virginia 22060-5606

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1991

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Site Characterization for Remote Minefield Detection Scanner (REMIDS) System Data Acquisition

5. FUNDING NUMBERS

6. AUTHOR(S)
Katherine S. Long, Kenneth G. Hall

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report EL-91-5

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Belvoir Research, Development, and Engineering Center
Fort Belvoir, VA 22060-5606

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE
classification

13. ABSTRACT *(Maximum 200 words)*

The purpose of this study was to collect ground truth data from various target arrays in several backgrounds under various environmental conditions to evaluate the performance of the Remote Minefield Detection Scanner (REMIDS). A test location in Warren County, Mississippi, was characterized during summer and fall conditions. Ground measurements included surface geometry, soils, quantitative and qualitative characterization of vegetation, onsite meteorology, and surface reflectance properties. State-of-the-art ground survey techniques were used to place and to locate precisely a collection of various US mine types--RAAM, M15, and M19--in configurations modified from those of current US Army doctrine. The REMIDS system uses both passive (thermal) and active (1.06-μm) lasers detector arrays. The test site was overflown several times in both the summer and fall seasons, so that data could be acquired for development and verification of automatic target recognition algorithms.

micrometers

14. SUBJECT TERMS

Ground truth	Minefield detection	Soils
Meteorology	Remote detection	Vegetation
Mine	Site characterization	

15. NUMBER OF PAGES
107

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

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PREFACE

Funds for the Standoff Minefield Detection System (STAMIDS) demonstration activities were provided by the US Army Belvoir Research, Development and Engineering Center under program order A9644. As part of an interagency agreement, the Corps of Engineers, with the US Army Engineer Waterways Experiment Station (WES) as the Executive Agent, is chartered with the technical demonstration of standoff minefield detection technology resulting from Army technology research and development. The field data collection was accomplished under the STAMIDS Demonstration Program, Mr. Kenneth G. Hall, Principal Investigator.

The study was conducted by WES personnel during the periods of July 1989 and October-November 1989, under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory (EL), and Dr. Victor E. LaGarde III, Chief, Environmental Systems Division (ESD), EL, and under the direct supervision of Mr. Charles A. Miller, Acting Chief, Battlefield Environment Group (BEG), and Mr. Harold W. West, Chief, Environmental Assessment Group (EAG).

Ms. Katherine S. Long (BEG) prepared this report with significant contributions by Mr. Hall, who was responsible for the overall field data collection effort. In addition to Mr. Hall and Ms. Long, who jointly designed the field data collection plan, the WES field team included Messrs. Thomas E. Berry, Charles D. Hahn, Sean Brewer, David Cobb, Stephen Pranger, and Miss Terri Justice, all assigned to the EAG. Mr. David Meeker, BEG, was responsible for the collection and reduction of the ground truth reflectance data. Messrs. David Leese and Humphrey Barlow of the WES Instrumentation Services Division deployed the environmental ground sensors and continuous recorders.

Program Manager for the Mine/Countermine Program was Dr. Victor C. Barber, EL, and Technical Team Leader of the Remote Minefield Detection Team was Dr. Daniel H. Cress, Research Group, ESD. The Remote Minefield Detection Scanner (REMIDS) Technical Research and Development Team was responsible for the REMIDS multisensor electronic, optical, and computer image processing hardware. Led by Dr. Cress, the technical team included Messrs. John H. Ballard, Raymond Castellane, Ernesto Cespedes, Ricky Goodson, Billy Helmuth, Willie Hughes, Brian Miles, Perry Smith, and Alfonso Vazquez, all of BEG. Results of the image data collection and processing will appear in a later report.

Commander and Director of WES during the conduct of the study and preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

Long, K. S., and Hall, K. G. 1991. "Site Characterization for Remote Minefield Detection Scanner (REMIDS) System Data Acquisition," Technical Report EL-91-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

SITE CHARACTERIZATION FOR REMOTE MINEFIELD DETECTION SCANNER (REMIDS) SYSTEM DATA ACQUISITION

PART I: INTRODUCTION

Background

1. Since World War II, mine use technology development has outstripped mine detection technology development. In recent years it has become apparent that the ability to detect friendly as well as unfriendly minefields is important in ensuring the safety of troops and civilians not only during periods of active conflict but also after the conflict is over. Serious shortcomings in countermine capabilities were recognized by the US Army Science Board Summer Study of 1986.

2. Prior to this official finding, the Environmental Systems Division (ESD) of the US Army Engineer Waterways Experiment Station (WES) initiated work in 1982 that resulted in the sensor system known as the Remote Minefield Detection Scanner (REMIDS) System (Cespedes and Cress 1986; Cespedes, Goodson, and Ginsberg 1988; Cress, Flohr, and Carnes 1984; Cress, Cespedes, and Ginsberg 1987; Cress, Goodson, and Cespedes 1986; Cress and Smith 1984, 1985; Goodson, Cress, and Cespedes 1988; Hansen 1986;* Hansen et al. 1988). The airborne scanner portion of this sensor has been tested in several environments using an assortment of targets and backgrounds. Ground truth data have been collected to evaluate and to verify data on ground targets and backgrounds collected by various sensors (Long 1990; Sabol and Hall, in preparation).

3. A US Army Standoff Minefield Detection System (STAMIDS) was to evolve from these efforts. A team was formed of WES personnel (the STAMIDS Technical Demonstration Team) to perform ground truth determinations against which to evaluate the performance of various candidate systems, including the REMIDS, to be considered in the development of the STAMIDS. The Technical Demonstration Team designed the test and reported the results that appear herein.

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* Personal Communication, 1986, G. M. Hansen, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Purpose and Scope of Work

4. The purpose of the exercise reported here was to collect ground truth data from various target arrays in several backgrounds under various environmental conditions to evaluate the performance of the REMIDS sensor configuration on an airborne platform. Several runs of the sensor were made over each area during the times in which the targets were in place. A relatively homogeneous, though "natural," background of surface geometry and composition as well as vegetation cover was chosen to minimize variables.

5. In July 1989 the WES Technical Demonstration Team laid out a test area near US Highway 61, south of the city of Vicksburg, MS, and west of the Vicksburg Municipal Airport. The WES ESD Technical Demonstration Team's scope of work included preflight site characterization by means of measurement of surface geometry, determination of surface composition (soils), quantitative and qualitative characterization of vegetation, and onsite meteorology (during the times including the REMIDS overflights). Ground measurements of surface reflectance properties in the near infrared and thermal values of targets and backgrounds were collected, some concurrent with specific overflights, while others were collected at other times during the characterization of the site in both July and October 1989.

6. In October 1989 the targets were again emplaced, using a portion of the test area used in July. Modifications to both procedures and layout design were incorporated in the October tests from lessons learned from the July tests. Ground data collected during the course of these tests were reduced to a form likely to contribute to the analysis of the REMIDS images, and they are presented in the following sections. Because of the time constraints, only limited statistics were generated using the ground truth data collected.

PART II: METHODS AND MATERIALS

Site Selection

7. The site selected for the 1989 southeastern continental United States testing of the REMIDS is located in an area immediately west of the Vicksburg Municipal Airport, about 8 miles* south of Vicksburg on Highway 61 (Figure 1). The site was selected because it met the requirements of a

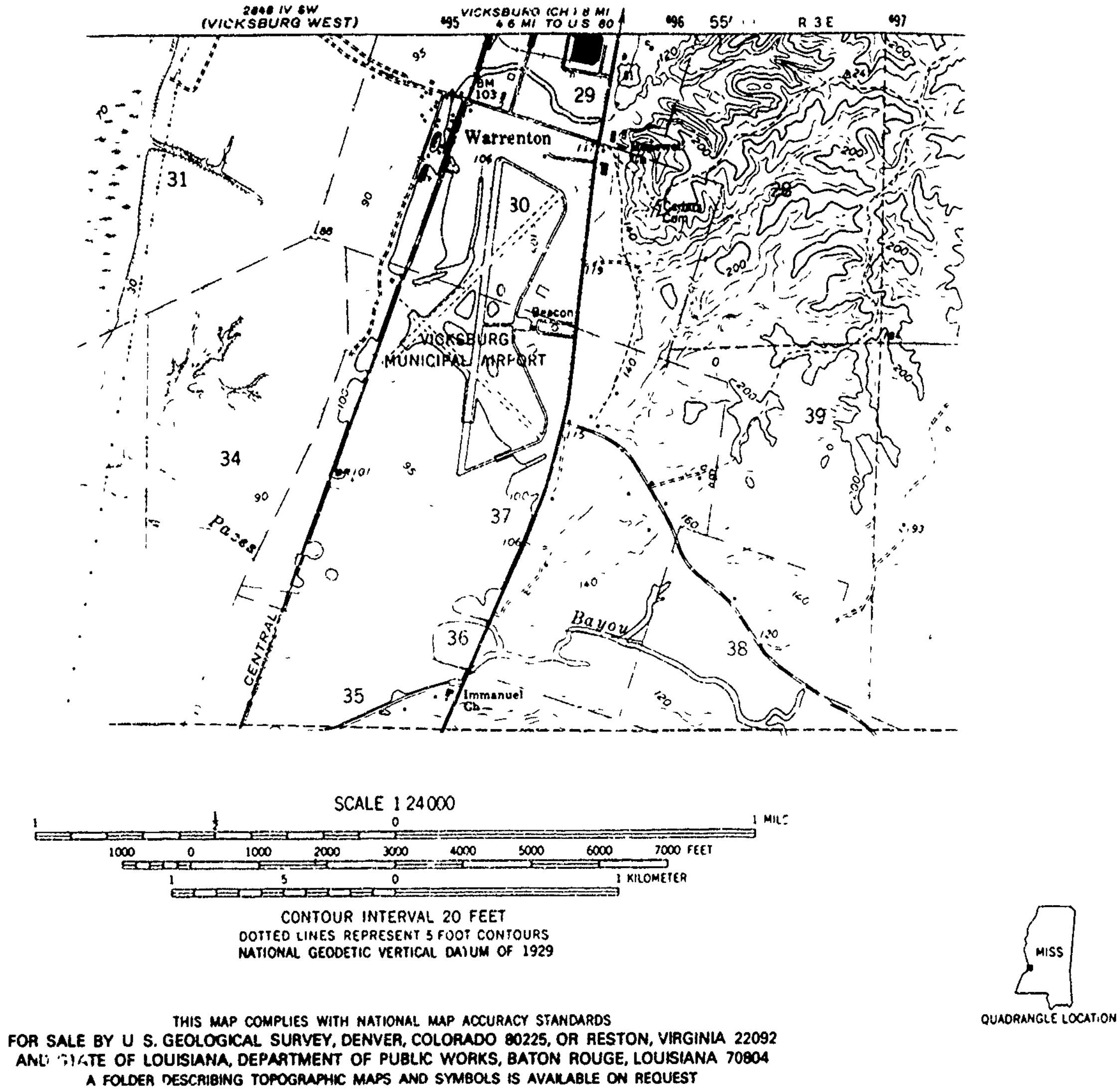

Figure 1. Location of test area
(map reduced from Yokena Quadrangle, Mississippi-Louisiana, 7.5 Minute Series)

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

proposed minefield (tank trafficability) and because of its close proximity to an airport and to WES, simplifying the logistics of conducting air and ground activities. Airborne platform and sensor maintenance tasks were conducted in a hangar located at the Vicksburg Municipal Airport.

Parameters Measured

Soils

8. Field analysis included measurement of moisture content and density, as well as cone penetrometer measurements. Laboratory analyses were performed on the bulk samples collected to determine the following:

- a. Specific gravity.
- b. Grain size distribution.
  1. Sieve analysis.
  2. Hydrometer analysis.
- c. Unified Soil Classification.
- d. Atterberg limits (plastic limit, liquid limit, plasticity index).
- e. Organic content.

For a description of these tests, see Appendix A. Cone penetrometer readings were also taken at each of the three sites.

Vegetation

9. Previous to the July overflights, the vegetative sampling performed included identifying prevalent species, measuring physical sizes of individual plants, and determining the density (individuals per unit area) of the plants. Representative samples of all prevalent herbaceous species were clipped just above the ground surface and were used for identification and for acquiring size data. Plant samples and density information were taken along the center-line from north to south of the grassy field (site A) every 65 m. Plant height, leaf length, leaf width, and crown height were measured with a metre stick and recorded for each sample. The representative number of plants per unit was determined with a 1-m by 1-m grid frame. This aluminum frame was subdivided with fine wire into 100 squares, each 10 cm by 10 cm (Figure 2). The percentage of vegetative cover was found by counting the number of squares in the grid containing bare soil and subtracting that value from 100. The percentage of cover by each prevalent species was estimated by counting the number of squares in which a plant type was predominant. Because the grid

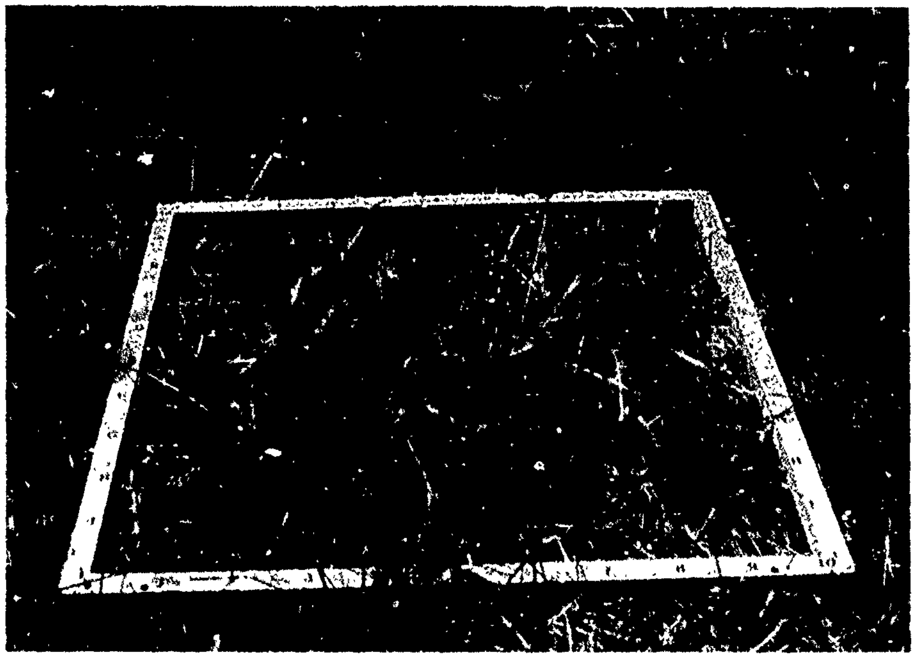

Figure 2. Grid for coverage estimate of nonwoody vegetation

contained 100 squares, these numbers correspond directly to a percentage of cover. Number of individuals was estimated by multiplying the number in a "typical" square times the number of squares containing the plant.

10. Species density for the hardwood area was found by using the structural cell sampling method (West et al. 1966; US Army Engineer Waterways Experiment Station 1968). This method requires choosing attributes of plants within a homogeneous assemblage to be characterized and finding the radius required to encompass a given number (usually 20) of the individuals possessing the specified set of attributes ("determinant") as the chosen tree. This radius defines the circle on the ground known as the "structural cell," which in turn can be converted to a density (number of trees per unit area). Species density for the pine areas was determined by measuring the regular grid spacing and extrapolating to numbers per acre (or hectare).

11. In October, vegetation data collected were largely restricted to qualitative descriptors.

Meteorology

12. The micrologger setups were placed in the test site to record data from meteorological sensors and from the "staring" radiometers, devices which measure apparent radiometric temperatures of the mines, the calibration targets (blackbodies), and the background surrounding them. All mines, sensors,

and special targets throughout the entire test field were located relative to the test site using standard survey techniques.

Polarization and reflectance

13. The WES Battlefield Environment Group, in support of REMIDS development, has developed a device for measuring relative reflectance in backscatter and degree of polarization. This device is known as the active reflectometer polarization instrument (ARPI). The ARPI device is designed to measure retro-reflected polarized laser return at 1.06 μm from natural backgrounds under field conditions at near-normal incidence. The ARPI unit directs a polarized laser beam toward the surface of the terrain area using the same optical path that is viewed by a set of matched, cross-polarized detectors. The ARPI in use is shown in Figure 3. Additional information about the ARPI is contained in Appendix B.

Figure 3. The active reflected polarization instrument (ARPI)

PART III: DATA COLLECTION AND PRESENTATION

July Exercises

General

14. The main data collection site was a long (approximately 800 m), narrow, grass-covered field adjacent and parallel to the runway at the Vicksburg Municipal Airport. The field was separated into two different sections by a drainage ditch. The northern three-quarters of the test field was used as the target emplacement area, while the southern one-quarter of the field was used as the special target/sensor calibration area. The entire area had been used for cropland until recent years. At the time of the tests reported here, the vegetation cover was principally "volunteer" grasses, with furrows still evident on the soil surface from the earlier row-crop practice. Soils data and both quantitative and qualitative vegetation data were taken at the time of the tests. Pertinent meteorological measurements were made throughout the testing period. Other areas were characterized for background only, and large target arrays were not placed within them.

Soils

15. The soil texture was fairly uniform, a sandy, silty clay, rich in organic content, a soil typically found in a floodplain with a history of tillage.

16. Soil samples were taken at the airport test site, in the cotton field, and in the soybean field. Soil description involved cone penetrometer sampling, visual observation, and bulk sampling for subsequent laboratory analysis described further in Appendix A. Visual observation of the soils in each area revealed high similarity among them, not surprising because all were located in an active floodplain. The soil texture throughout the individual test sites was determined to be uniform. A bulk sample was taken from 0-6 in. (0-15 cm) of the surface soil at representative locations. The uniformity of the soil justified only a few soil samples, three being used to represent the area of study. The results of the soils measurements and analysis can be found in Table 1. Cone penetrometer values obtained are shown in Figure 4. Results of laboratory studies are shown in Figure 5.

Table 1

Cone Penetrometer Data, July 1989

	Airport Test Site							
	Stake 1				Stake 2			
Depth in.	Reading 1	Reading 2	Reading 3	Mean	Reading 1	Reading 2	Reading 3	Mean
0	70	120	50	80	40	30	50	40
1	150	170	140	153	50	50	90	63
2	190	240	130	187	160	120	80	120
3	350	310	240	300	240	160	70	157
4	400	410	370	393	380	220	70	223
5	510	440	440	463	450	260	100	270
6	540	500	490	510	390	300	200	297
9	410	640	570	540	320	400	300	340
12	620	580	450	550	210	340	550	367
15	360	260	250	290	400	*	300	233
18	550	300	390	413	400	*	350	*250
	Stake 3				Stake 4			
0	20	20	50	30	100	160	150	137
1	50	30	90	57	130	190	220	173
2	210	50	140	133	140	260	220	207
3	240	140	240	207	190	300	240	243
4	250	160	220	210	330	360	280	323
5	340	200	300	280	440	380	300	373
6	330	240	300	290	500	360	450	437
9	390	340	200	310	610	350	750	570
12	280	310	310	300	620	510	600	577
15	210	240	280	243	740	640	640	673
18	230	310	310	283	750	610	600	653

	Cotton Field Test Site			
Depth, in.	Reading 1	Reading 2	Reading 3	Mean
0	120	50	50	73
1	400	400	140	313
2	580	520	390	497
3	530	450	400	460
4	520	400	300	407
5	500	390	270	387
6	380	400	250	343
9	360	240	280	293
12	290	200	390	293
15	190	130	190	170
18	140	240	150	177

(Continued)

* Rod fell through.

(Sheet 1 of 4)

Table 1 (Continued)

Depth, in.	Soybean Field Test Site Reading 1	Reading 2	Reading 3	Mean
0	70	50	100	73
1	350	410	120	293
2	510	430	400	447
3	360	360	350	357
4	350	390	330	357
5	410	460	400	423
6	450	290	620	453
9	450	300	500	417
12	250	100	450	267
15	140	240	300	227
18	170	250	360	260

Airport Test Site

Depth in.	Stake 1 Reading 1	Reading 2	Reading 3	Mean	Stake 2 Reading 1	Reading 2	Reading 3	Mean
0	70	120	50	80	40	30	50	40
1	150	170	140	153	50	50	90	63
2	190	240	130	187	160	120	80	120
3	350	310	240	300	240	160	70	157
4	400	410	370	393	380	220	70	223
5	510	440	440	463	450	260	100	270
6	540	500	490	510	390	300	200	297
9	410	640	570	540	320	400	300	340
12	620	580	450	550	210	340	550	367
15	360	260	250	290	400	0*	300	233*
18	550	300	390	413	400	0*	350	250*
	Stake 3				Stake 4			
0	20	20	50	30	100	160	150	137
1	50	30	90	57	130	190	200	173
2	210	50	140	133	140	260	220	207
3	240	140	240	207	190	300	240	243
4	250	160	220	210	330	360	280	323
5	340	200	300	280	440	380	300	373
6	330	240	300	290	500	360	450	437
9	390	340	200	310	610	350	750	570**
12	280	310	310	300	620	510	600	577
15	210	240	280	243	740	640	640	673
18	230	310	310	283	750	610	600	653**

(Continued)

* Rod fell through.

** Contains a reading of 750 corresponding to off the scale.

(Sheet 2 of 4)

Table 1 (Continued)

Depth, in.	Cotton Field Test Site Reading 1	Reading 2	Reading 3	Mean
0	120	50	50	73
1	400	400	140	313
2	580	520	390	497
3	530	450	400	460
4	520	400	300	407
5	500	390	270	387
6	380	400	250	343
9	360	240	280	293
12	290	200	390	293
15	190	130	190	170
18	140	240	150	177

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12	250	100	450	267
15	140	240	300	227
18	170	250	360	260

	Airport Test Site							
	Stake 1				Stake 2			
Depth in.	Reading 1	Reading 2	Reading 3	Mean	Reading 1	Reading 2	Reading 3	Mean
0	70	120	50	80	40	30	50	40
1	150	170	140	153	50	50	90	63
2	190	240	130	187	160	120	80	120
3	350	310	240	300	240	160	70	157
4	400	410	370	393	380	220	70	223
5	510	440	440	463	450	260	100	270
6	540	500	490	510	390	300	200	297
9	410	640	570	540	320	400	300	340
12	620	580	450	550	210	340	550	367
15	360	260	250	290	400	0*	300	233*
18	550	300	390	413	400	0*	350	250*

(Continued)

* Rod fell through.

(Sheet 3 of 4)

Table 1 (Concluded)

	Airport Test Site							
	Stake 3				Stake 4			
Depth in.	Reading 1	Reading 2	Reading 3	Mean	Reading 1	Reading 2	Reading 3	Mean
0	20	20	50	30	100	160	150	137
1	50	30	90	57	130	190	200	173
2	210	50	140	133	140	260	220	207
3	240	140	240	207	190	300	240	243
4	250	160	220	210	330	360	280	323
5	340	200	300	280	440	380	300	373
6	330	240	300	290	500	360	450	437
9	390	340	200	310	610	350	750	570*
12	280	310	310	300	620	510	600	577
15	210	240	280	243	740	640	640	673
18	230	310	310	283	750	610	600	653*

	Cotton Field Test Site			
Depth, in.	Reading 1	Reading 2	Reading 3	Mean
0	120	50	50	73
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9	360	240	280	293
12	290	200	390	293
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18	140	240	150	177

	Soybean Field Test Site			
Depth, in.	Reading 1	Reading 2	Reading 3	Mean
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2	510	430	400	447
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4	350	390	330	357
5	410	460	400	423
6	450	290	620	453
9	450	300	500	417
12	250	100	450	267
15	140	240	300	227
18	170	250	360	260

* Contains a reading of 750 corresponding to off the scale.

(Sheet 4 of 4)

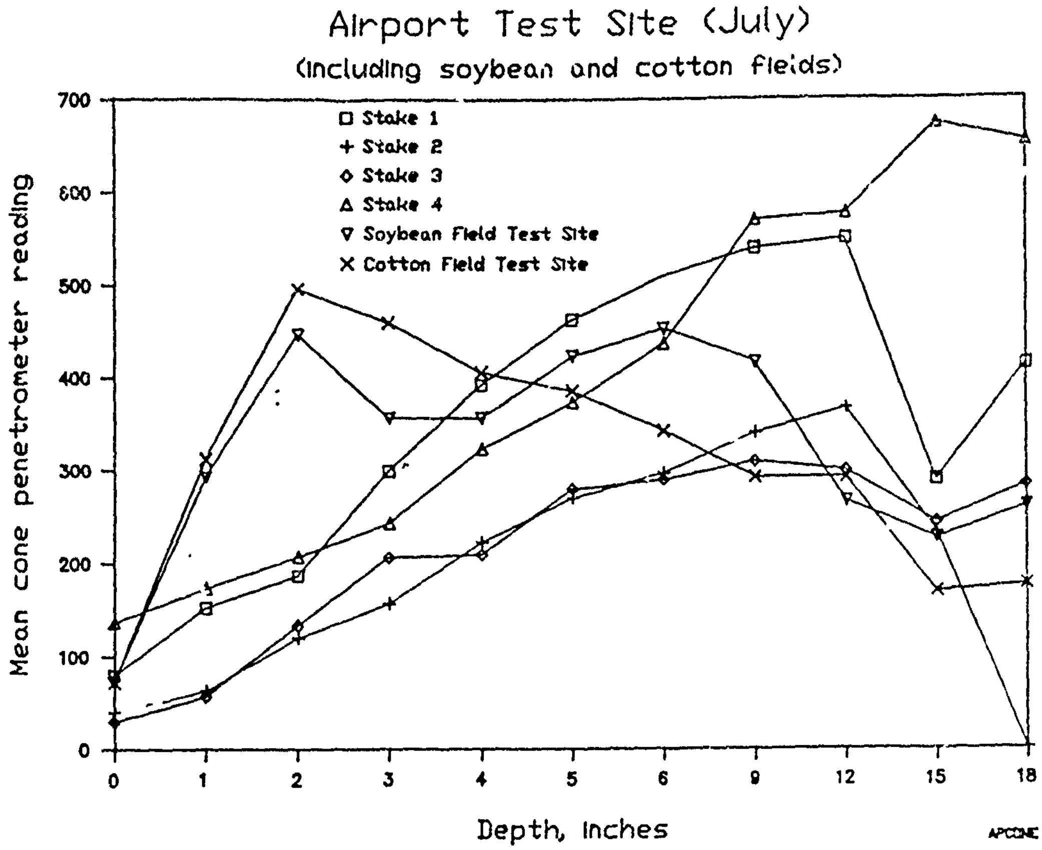


Figure 4 Cone penetrometer values

Vegetation

17. The test site used in the July exercises encompassed areas containing five distinct vegetation types typical of floodplain development in areas along the Mississippi River

18. The first site (site A) (Figure 6) contained grassy fields that had been plowed until about 2 years before, but since then had not been cultivated but rather had been allowed to revert to mostly native or naturalized grasses with occasional forbs. The second (site B) (Figure 7) was a planted pine stand about 15 to 20 years old at the time of this study. The third (site C) (Figure 8) was a stand of hardwoods, predominantly sweet gum trees. The fourth (site D) (Figure 9) was a skip-row planted cotton field, and the fifth (site E) (Figure 10) was a soybean field.

19. Site A, the grassy location, was chosen as the primary data collection site and was divided into four separate target areas. The other four sites (B, C, D, and E) were used as secondary sites, their primary purpose being to serve as thermal imaging targets representing local vegetation types to be used in background contrast and comparison analysis.

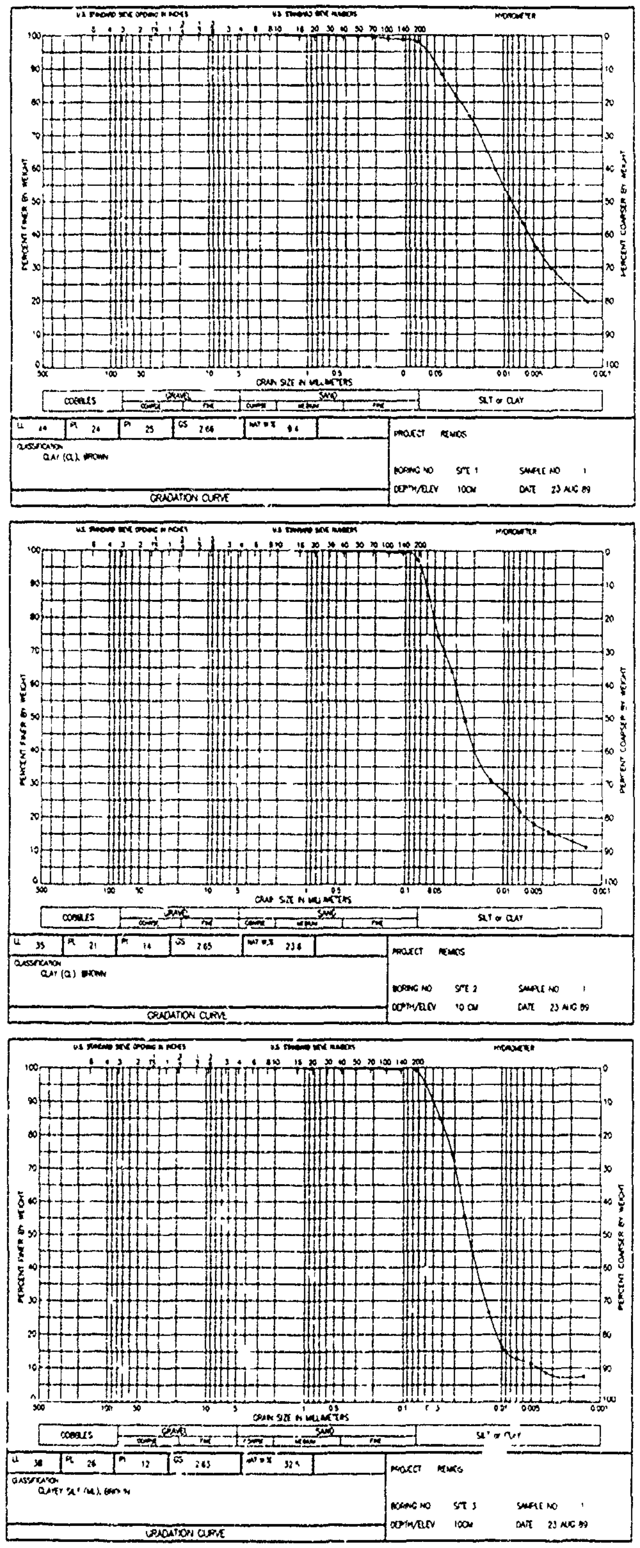


Figure 5. Soil gradation sheet

Figure 6. Site A - grassy field

Figure 7. Site B - planted pine stand

Figure 8. Site C - hardwood stand

Figure 9. Site D - cotton field

Figure 10. Site E - soybean field

Grassy field

20. This field (site A) exhibited nearly total grassy cover, except for a few low spots of standing water and other small areas bare of significant vegetation. The northern section of the test area had been mowed 2 weeks prior to testing. At the time of testing, the vegetation was less than 1 m in height, unlike the southern section, which had not been mowed recently and had grasses reaching 3 m (Figure 6).

21. The results of the vegetation measurements of site A (Figure 6) can be seen in Table 2. The predominant species found were Johnson grass (*Sorghum halepense* (L.) Pers.), Bermuda grass (*Cynodon dactylon* (L.) Pers.), Dallis grass (*Paspalum dilatatum* Poir.), curled dock (*Rumex* sp.), a sedge (nutgrass) (*Cyperus rotundus* L.), unidentified forbs, and purslane (*Portulaca* sp.), a succulent creeping plant (Correll and Correll 1975; Gleason and Cronquist 1963).

Pine stand

22. Site B (Figure 7) included a planted stand of pines approximately 15 to 20 years old arranged in two different grid schemes. These stands were located southeast of the airport test field. Both stands appeared to be about the same age. Adjacent to one of the stands was a patch of pines killed by the Southern pine beetle. However, the remaining area of that stand (Table 3)

Table 2

Quantitative Vegetation Data, Grassy Site

Plot Number	Plant Number	Distance, from N bound, m	Plant Height cm	Crown Width cm	Plant Type (Common Name)	Leaf Width cm	Leaf Length cm	Coverage Parameters A*	B**	Number/ m-sq (A × B)	Photos Roll, Frame
1	1	5	50		Johnson grass	2.5	40	1	50	50	1,14
1	2	5	30	10	Bermuda grass	0.2	10	5	80	400	1,14
2	1	65	50		Johnson grass	[illegible]	43	1	25	25	1,15
2	2	65	30	10	Bermuda grass	0.2	10	5	85	425	1,15
3	1	125	50		Dallis grass	1	40	2	85	170	1,16
	2				Sedges						
	3				Sour dock						
4	1	190	25		Dallis grass	1	21	1	50	50	1,17
4	2	190	35		Johnson grass	2	30	1	20	20	1,17
5	1	255	25		Dallis grass	0.5	23	1	70	70	1,18
	2				Sedges						
6	1	320	24		Dallis grass	0.5	20	1	40	40	1,19
6	2	320	70		Johnson grass	2	50	1	40	40	1,19
6	3	320	32	24	Sour dock	4.5	17	1	20	20	1,19
7	1	385	25		Dallis grass	0.5	20	1	50	50	1,20
7	2	385	30	20	Sour dock	4.5	15	1	10	10	1,20
8	1	450	48		Dallis grass	1	35	1	15	15	1,21
8	2	450	70		Johnson grass	2	37	1	10	10	1,21
	3				Sedges						
9	1	515	50		Dallis grass	1	40	1	40	40	1,21
9	2	515	10	10	Purslane	0.5	1	3	40	120	1,22
10	1	580	30		Dallis grass	0.5	23	1	50	50	NONE
10	2	580	40		Johnson grass	2.5	28	1	5	5	NONE

* Number of individuals in one 10-cm by 10-cm square.
** Number of squares occupied by that plant type.

Table 3

Quantitative Vegetation Data, Forested Sites

	Plot 1*		Plot 2**				Plot 3†		
	dbh cm	Height ft	dbh, cm Live	dbh, cm Dead	Height, ft Live	Height, ft Dead	Circumference cm	dbh, cm	Height
	14.0		18	16	42.3	30	15.2	47.8	
	18.0	49	16.3	14			10.3	32.4	
	20.0	40	17.5	13.5			9	28.3	
	20.5	45	14.3	14.2			117.5	369.1	
			21.4	15			29.3	92.0	85
			18.6	13.2			6.7	21.0	
			15.9	11.5			11.2	35.2	
							6.7	21.0	
							11.2	35.2	
							6.7	21.0	
							8.8	27.6	
							16.9	53.1	69
							14.3	44.9	
							5.5	17.3	
							6.3	19.8	35.5
							11.5	36.1	
							16.6	52.2	
							9	28.3	
							6.9	21.7	
							16.5	51.8	
							14.4	45.2	
							8.7	27.3	
Mean	18.3	45	17.4	13.9			16.3	51.3	
Standard deviation	2.3	4	2.1	1.3			22.7	71.3	

* Planted pines on 6- by 8-ft grid; N = 9 alive, 2 dead.
** Planted pines, mostly dead, on 6- by 6-ft grid.
† Hardwoods, mostly sweetgum, modified structural cell, 1,031 sweetgum/acre, 20 trees in circle of 5 m.

and the second stand showed no obvious damage. The patch containing the dead trees was planted about 6 ft apart in rows that were 6 ft from the adjacent row, resulting in a density of about 1,210 trees per acre (3,000 trees per hectare) assuming a 100-percent survival rate. The other stand was planted in rows with trees about 6 ft apart as well. Each adjacent row was separated by about 8 ft, implying a density of about 908 trees per acre (about 1,270 trees per hectare). In this case, however, approximately 18 percent had died or were missing from the pattern; consequently, the density was only around 740 trees per acre (about 1,840 trees per hectare). The live trees and the dead trees were generally the same height, but the dead trees had smaller diameters.

23. The live pine stands contained some hardwoods in the understory, such as sweet gum (*Liquidambar styruciflua* L.), oak (*Quercus* sp.), and Eastern red cedar (*Juniperus virginiana* L.). The dead pine stand had been invaded by box elder (*Acer Negundo* L.) and sweet gum approximately 3 m tall. The second pine stand averaged a height of 45 ft (13.7 m) and a diameter of 18.3 cm. The rows were planted on a bearing of 255 deg. The dead patch of trees in the first stand averaged 30 ft (9.1 m) in height and 5.47 in. (13.9 cm) in diameter. The live trees were a bit larger, averaging 42 ft (12.9 m) in height and 6.85 in. (17.4 cm) in diameter. Detailed measurements are given in Table 3.

Hardwood stand

24. Site C (Figure 8) contained a stand of hardwoods, mostly sweet gum, located near the pine forests. These trees existed in a "natural" forested pattern as opposed to the row patterns of the pine stands. The diameters of representative trees at breast height (dbh) were measured. The average dbh was 4.7 in. (12.1 cm) with a range of 2.1 to 11.5 in. A radius of 5 m (area = 78.5 sq m) was required to encompass 20 of the sweet gum trees, yielding a plant density of 0.25 plant per square metre, or about 2,500 trees per hectare (1,000 per acre). The mean height of the trees as determined by a clinometer was 63.2 ft (19.3 m), ranging from a small, young tree at 35.5 ft (10.8 m) to the tallest tree at 85 ft (25.9 m) (see Table 3).

Cotton field

25. Site D (Figure 9) was located in a cotton field south of the airport test site in a Mississippi River floodplain. The cotton plants had reached full vegetative growth; i.e., they were fully leafed out, they had reached a mature height, and they were blooming. Soil in the field is typical

of an alluvial formation: by visual inspection, a sandy, silty clay rich in organic matter. The cotton was planted using the skip-row method (two adjacent rows of cotton alternated with an empty row constituting the basic element of the planting pattern) with the rows running on a bearing of 270 deg. One cycle of planting (i.e., two rows of cotton and one empty row) occurred approximately every 8.2 ft (2.5 m). The plants in adjacent rows were planted on 36-in. (0.91-m) centers with an average plant density of 13 stems in a 1-m distance. Throughout the field, the plants were generally uniform. The average plant height was 1 m and the average plant crown width was just under 1 m.

Soybean field

26. Site E (Figure 10) was located in a soybean field near the cotton field site. The plants had reached vegetative maturity. The soil of the area was typical of alluvial soils built up from flood deposits, being a sandy, silty clay high in organic content. The beans were planted in traditional rows spaced 30 in. (760 cm) apart on a bearing of 0 deg (magnetic North). The plants in the field were fairly uniform in height and density, with the average plant height just under 1 m. The average plant crown width was 28 in. (700 cm). Because the plant crowns of adjacent rows touched each other, the middles (spaces between rows) were scarcely visible from above. The average density of the plants along a row was 19 stems in a 1-m distance.

Meteorology

27. An example of meteorological data recorded throughout the test can be found in Figure 11. The complete record spanning 12 July through 24 July is found in Appendix C For the July 1989 exercise, relative humidity, air temperature, precipitation, solar loading, soil temperature at three depths, and wind velocity were recorded from 1100 hr, 12 July through 2400 hr, 13 July; 2400 hr, 14 July through 2400 hr, 16 July; 100 hr, 21 July through 2400 hr, 22 July; 0030 hr, 24 July through 2400 hr, 24 July.

28. An example of thermal data giving the recorded temperatures of entities shown in Figure 12 spanned, with some interruptions, from 12 July through 24 July. Hatched bars indicate days of REMIDS overflights. The complete record is given in Appendix D.

Target areas

29. The three minefields, target areas 1, 3, and 4, were located in the northern section of the airport test field (site A) and were laid out to evaluate the sensors' ability to find the various mine/minefield types in a grassy

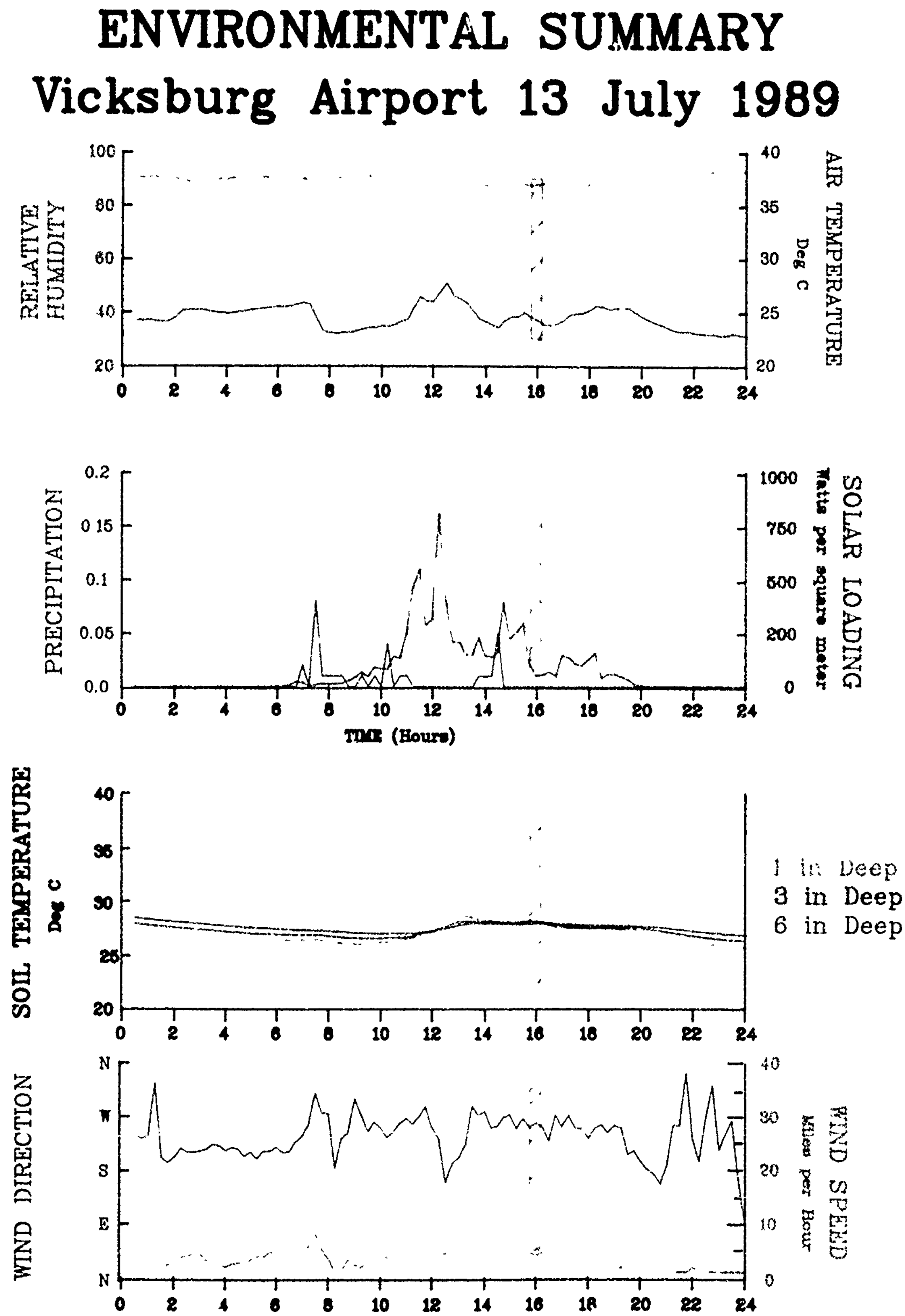


Figure 11. Example of meteorological record of July 1989 test period

Thermal Data
Vicksburg Airport 13 July 1989

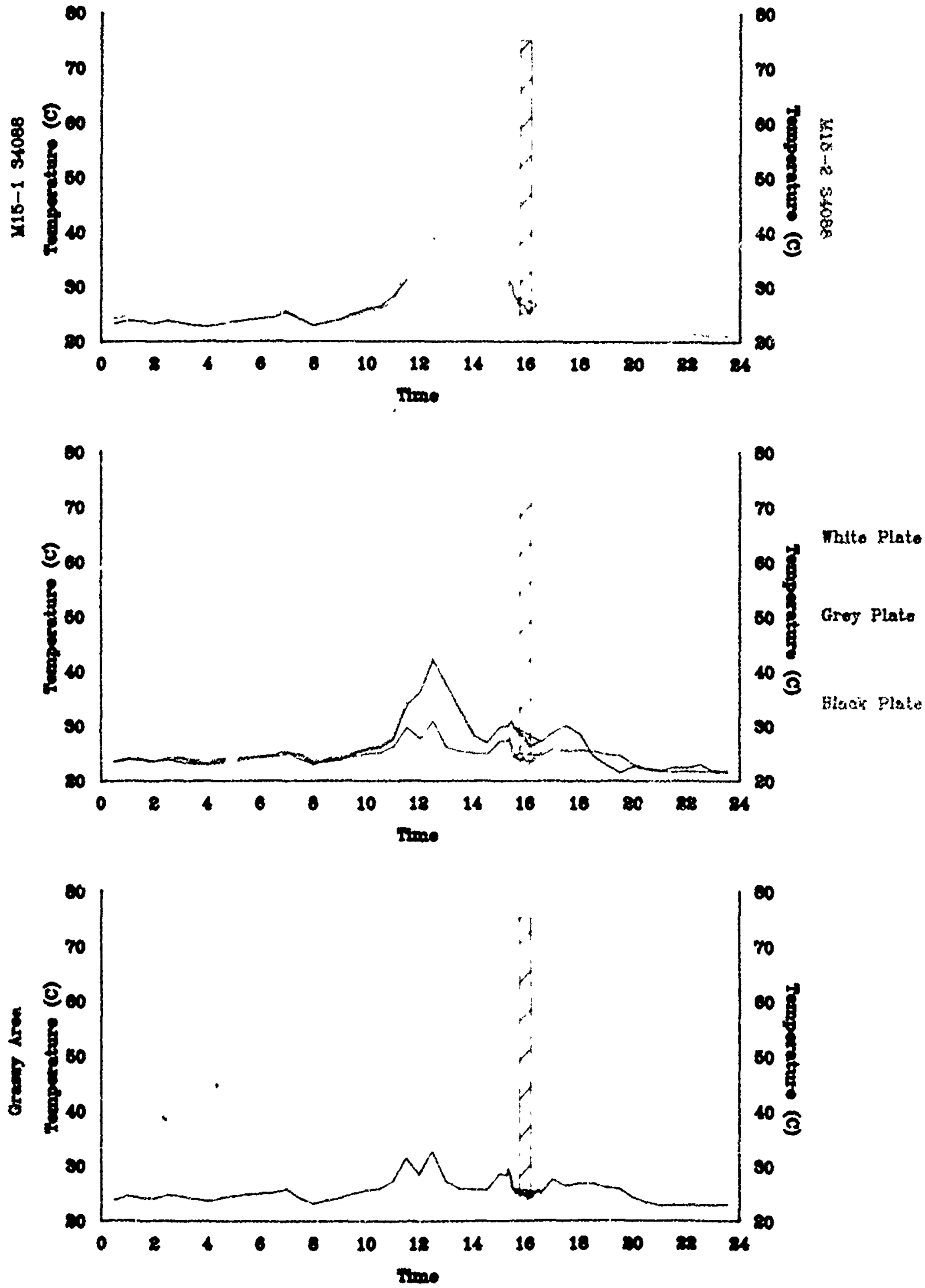


Figure 12. Example of thermal record of July 1989 test period

field. Target area 2 filled most of the southern section and was designated as the Special Targets Area (Figure 13).

30. Target area 1 was intended to simulate a 50-m by 50-m remote anti-armor mine system (RAAM) minefield. Forty-six M75 mines were "randomly" emplaced in the minefield at a realistic distribution but an increased density for artillery-delivered mines. (See Figure 14 for the specific configuration employed.) All mines were placed with the convex side upward. No attempt was made to simulate orientation such as that produced with an artillery delivery.

31. Target area 3 was a 70-m by 100-m M-19 antitank (AT) minefield (Figure 15). Forty-five mines were tactically emplaced according to newly developed doctrine (phased minefield pattern - Standard A) (US Army Engineer School 1988). This pattern dictates two straight rows of mines at each end of the area located 100 m apart with a row following an imaginary sinusoid through the middle. The mines were emplaced a nominal 3 m off the sinusoid, alternating left and right with each successive mine, resulting in a nominal spacing of the mines of 6 m.

32. Target area 4 was intended to simulate a 50-m by 100-m M-15 AT minefield. This minefield was emplaced using the same pattern as the M-19 field, again using 45 mines, resulting in a denser pattern because the field was smaller. As in the previous field, the mines were alternated left and right 3 m from the centerline, but this time the mines were emplaced 4 m apart on a line (Figure 16), resulting in a linear density of 0.9 mine per metre front.

33. Target area 2, also known as the Special Targets Area, was set up in the southern section of the test site, its primary purpose being sensor calibration. Surplus mines of the three types being tested were placed in known positions in this area, and the grass was removed so the sensor could have a clear line-of-sight to the mines. The secondary purpose of this field test was data collection from special targets, including 4-ft by 8-ft wooden panels painted black and white, 2-ft by 2-ft metal squares painted using various paints and colors, and painted pans of water. For a complete layout, see Figure 17.

ARPI data

34. Ground level measurements yielding percent polarization values are given in Table 4. Table 5 enumerates the targets and the polarization measurements obtained from these targets in the 24-27 July 1989 time frame. The

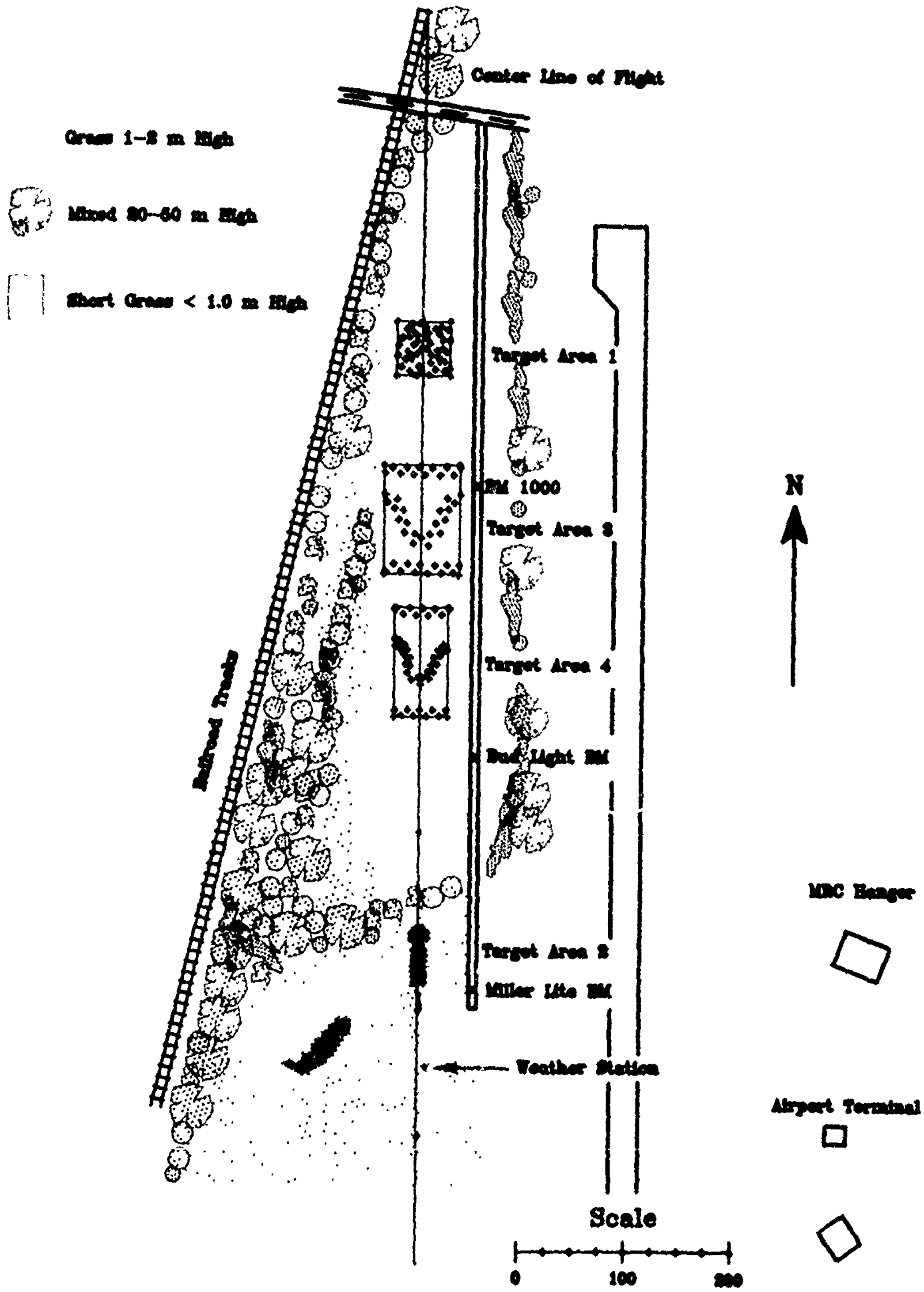


Figure 13. Location drawing of July test layout

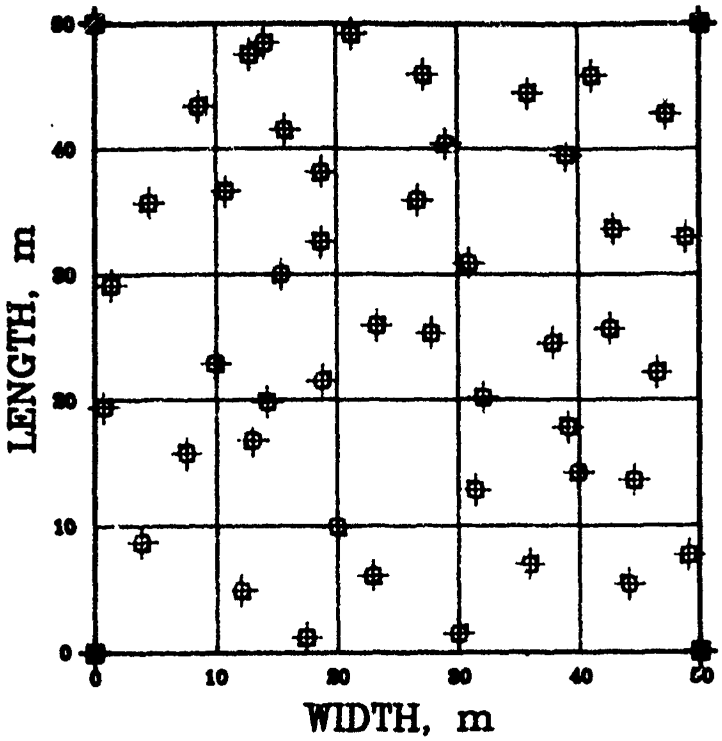


Figure 14. July RAAM (M75) target area 1

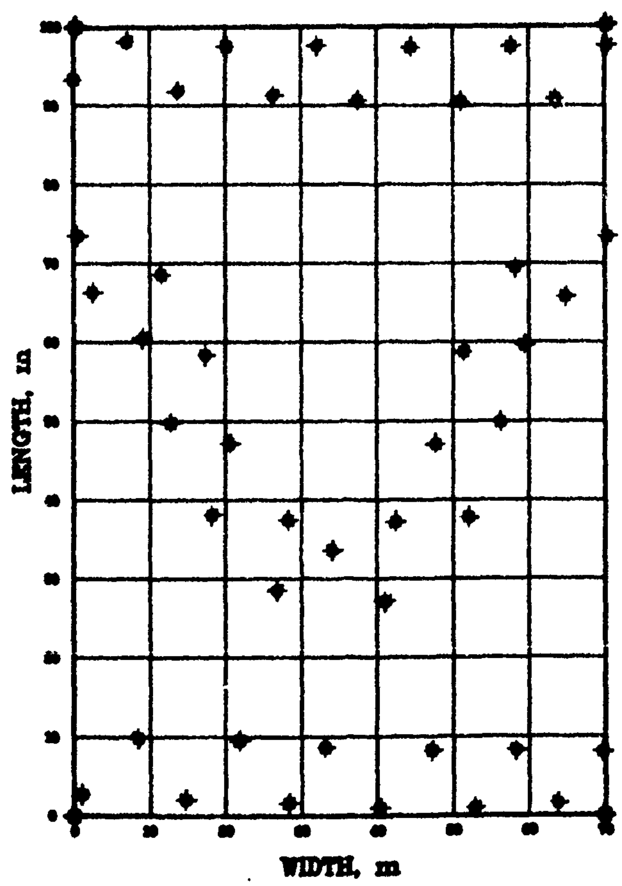


Figure 15. July M19 target area 3

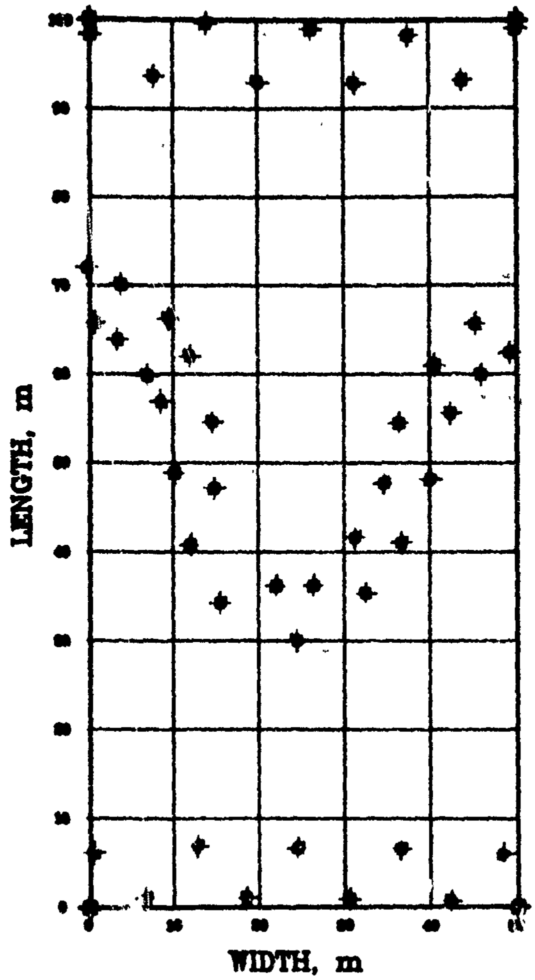


Figure 16. July M15 Target Area 4

view angles of the ARPI employed were 0, 10, and 20 deg. A summary of these measurements can be seen in Table 5 and Figure 18.

October Exercises

General

35. In the October exercise only site A was characterized and used for target array emplacement. Site A was well-covered with senescent Johnson grass as well as other occasional grasses and forbs. Site preparation began on this area situated between the airport and the railroad tracks on 3 October 1989, with the area north of the wooded ditchbank being mowed to about 0.5 m from the soil surface (Figure 19). The northernmost section of this field to the east-west hardtop road was left in its "natural" state, predominantly Johnson grass as tall as 3 m, with patches of still green Bermuda grass and

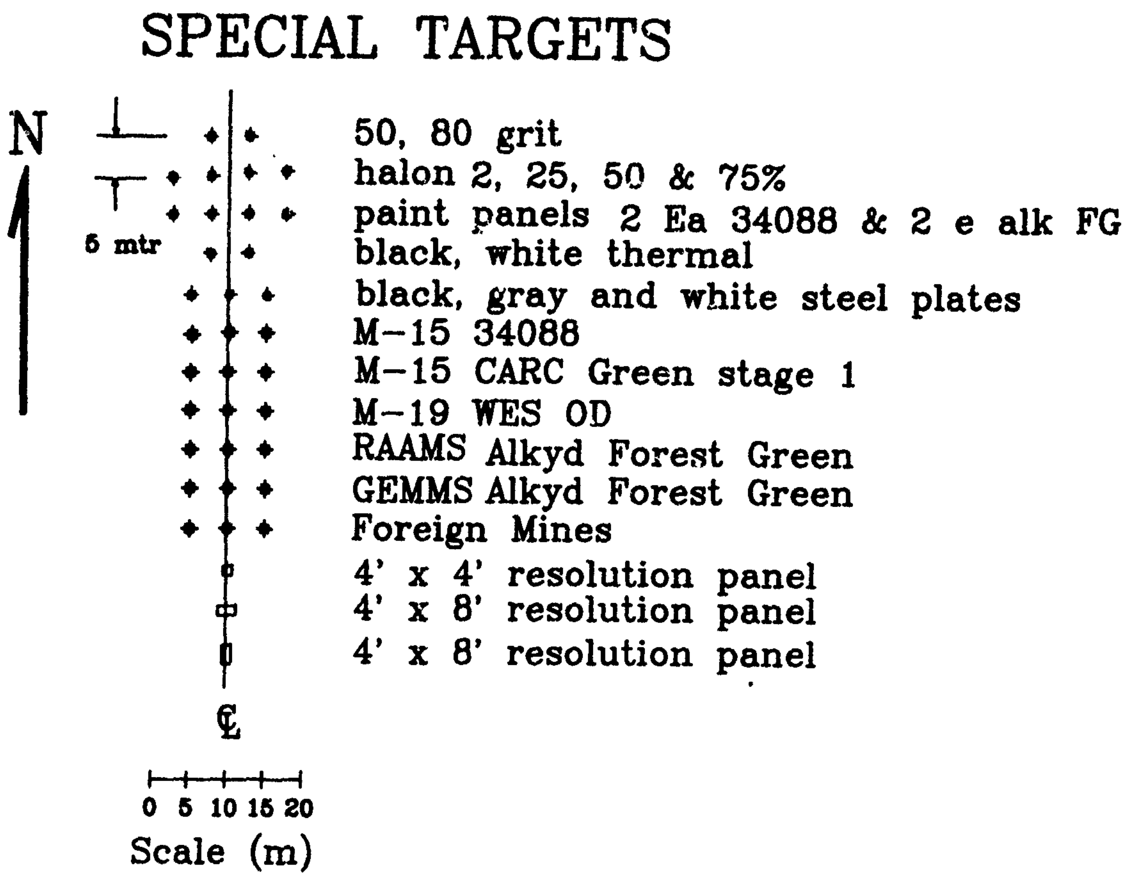


Figure 17. July calibration targets area 2

nut grass (purple nut sedge). The Johnson grass had fully mature fruiting bodies and its vegetative parts had turned brown. Because of the nature of the high, tough vegetation being mowed, patches of the grass were missed by the mower. This lent variability to the substrate (background) being prepared for mine placement.

Soils

36. Soils data were not collected for the October REMIDS exercise.

Vegetation

37. Vegetation data were not collected as intensively in October as in July. An aerial view including site A as it was being mowed is shown in Figure 20. The area mowed "high" would receive mines in the configuration shown in the northernmost portion of site A (Figure 21). A special area in the southern part of site A was prepared to include flat plowed, furrowed, short-mowed, medium-mowed, and "natural" strips 5 m wide with the longer side oriented in the east-west direction, normal to the proposed flight path.

Table 4

July Ground Reflectance Measurements

Measured Values*

Background Measurements

Surface	Polarization, Percent Mean
Mixed dead grass	24.6
Mixed dead grass	23.9
Bahia grass	9.5
Johnson grass	12.6
Nut grass	13.1
Cotton leaf	7.3
Bean leaf	14.0

Test Measurements

Surface	Polarization, Percent Angle 0.0	10.0	20.0	Mean	Standard Deviation
Mixed dead grass	29.1	23.1	21.7	24.6	3.2
Mixed dead grass	21.0	29.3	21.3	23.9	3.9
Bahia grass	13.7	8.7	6.3	9.5	3.1
Johnson grass	10.6	13.0	14.1	12.6	1.4
Nut grass	14.8	14.4	10.0	13.1	2.2
Cotton leaf	6.4	9.1	6.4	7.3	1.3
Bean leaf	15.5	14.8	11.7	14.0	1.6
Mean	15.9	16.1	13.1	15.0	2.4
Standard deviation	15.9	16.1	13.1	15.0	2.4

Special Targets	Polarization, Percent Mean
ALKYD FG	22.6
BASO4	22.3
FLINT 50	2.8
LBS02	82.3
LBS25	30.5
LBS50	16.8
LBS75	12.1
LBS99	8.9
OD 34088	87.4
STG1 383	17.9

ARPI Data From Countermeasures Handbook

Target	Polarization, Percent Angle 0.0	10.0	20.0	Mean	Standard Deviation
ALKYD FG	22.4	22.6	22.8	22.6	0.2
CARCGREEN	17.8	17.9	18.0	17.9	0.1
FLINT 50	2.9	2.7	2.7	2.8	0.1
GARNET 80	12.6	10.6	8.1	10.4	1.8
OD 34088	93.1	89.4	79.8	87.4	5.6

* Measurements from 0 to 20 deg across the entire field of view (FOV) (4 deg).

Table 5

ARPI Polarization Measurements After July 1989 REMIDS Tests

	Percent Polarization			
	Angle, degrees			
WES Targets	0.0	5.0	10.0	20.0
BaSO4	22.3	--	22.3	23.7
50%	20.2	--	18.6	16.5
25%	20.2	--	18.6	16.5
M19	44.8	--	43.9	43.0
M15	78.8	--	76.1	54.5
RAAM	25.2	--	25.9	25.1
BaSO4	22.3	--	22.7	23.4
Dead grass	29.1	--	23.1	21.7
Bare soil	22.3	--	22.1	23.1
Dead grass	21.0	--	29.3	21.3
Halon 50%	18.5	--	18.6	15.4
Bahia grass	13 7	--	8.7	6.3
Johnson grass	10.6	--	13.0	14.1
Bare soil	19.8	--	30.1	23.6
Nut grass	14.8	--	14.4	10.0
Water bog	27.6	23.6	23.0	27.9
Bare soil (cotton field)	19.6	--	21.5	18.9
Cotton leaf	6.4	--	9.1	6.4
Bean leaf	15.5	--	14.8	11.7

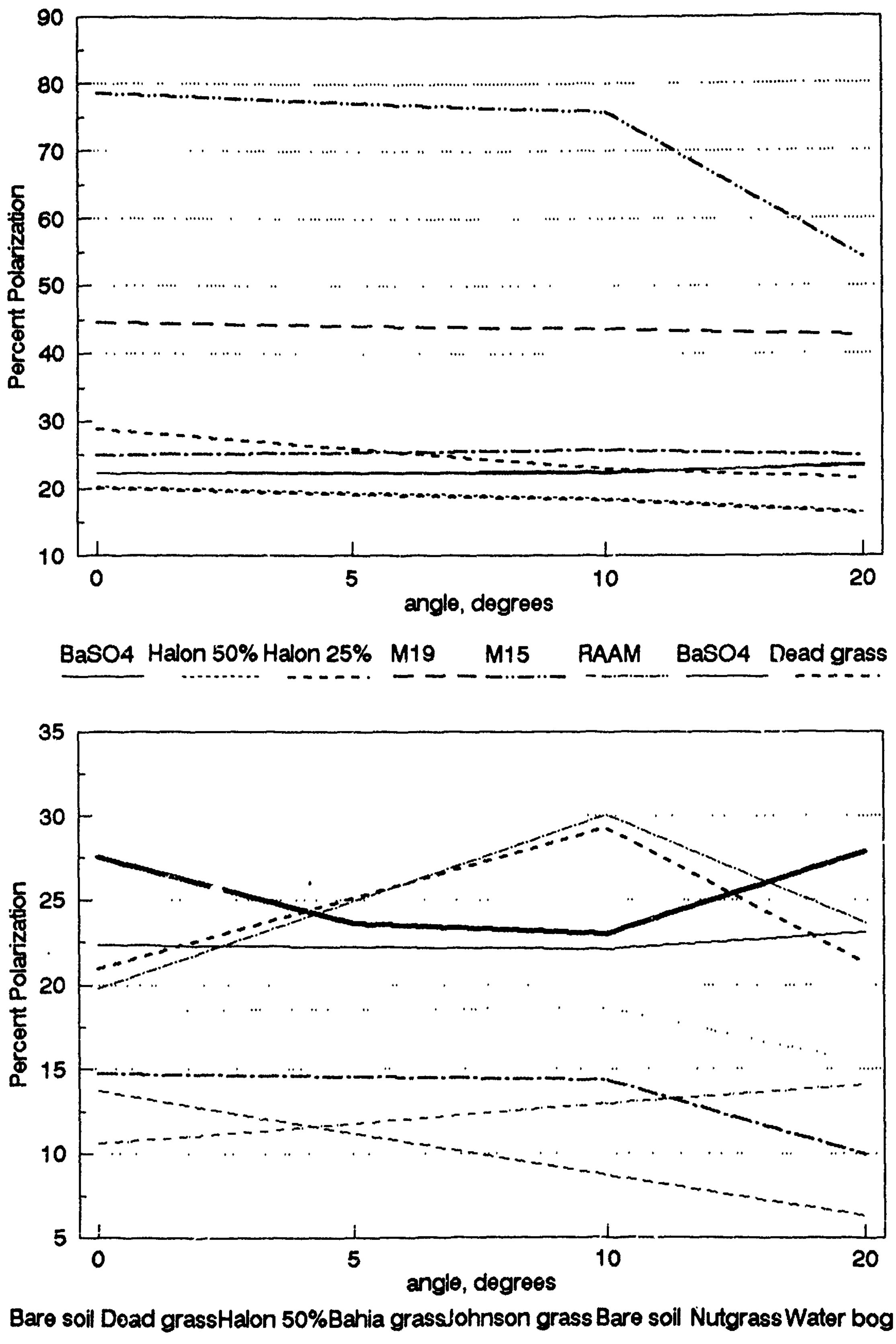


Figure 18. ARPI polarization measurements for special targets

Figure 19. Mowing the grassy field prior to target placement

Triads of M19, M75, and M15 mines were placed into each of four sections in each strip.

38. A qualitative inventory was made of the vegetation on the ditchbank on the south side of the field and between the railroad and the field. This inventory was conducted on 16 October 1989, so the condition of the vegetation where noted refers to an early west central Mississippi fall. No killing frost had yet occurred. The following numbering sequence begins at the intersection of the "blind" hardtop road parallel and west of the airport runway and the ditch that serves as the southern boundary of what is currently known as the Airport Test Target site A.

39. The numerals generally correspond to locations so identified on Figure 20 and appear in approximate order of decreasing biomass in each location.

1. Johnson grass, goldenrod, aster.
2. Black willows (N>15), cottonwood, +1., above.
3. Switch cane to 2 m.
4. Cottonwood, goldenrod (3 plants/sq m).
5. Willow, cottonwood, Johnson grass.

Figure 20. Airphoto of Site A, October exercises

6. Willows, sumacs, mixed Johnson grass and goldenrod, saw briers (in line with the middle of the target plots).

7. Break (two-thirds west of special target plot).

8. Cottonwood, willow (predominant at southwestern corner of site A).

9. Cottonwood (N=3), hickory, Johnson grass, goldenrod (between site A and railroad).

10. Cottonwood, willow, Johnson grass, goldenrod, and Bermuda on treeline. Willow, Johnson grass, goldenrod, and Bermuda near field.

11. Cottonwood, willow. Turn northward, cottonwood treeline between Johnson grass path and plots (west), Johnson grass

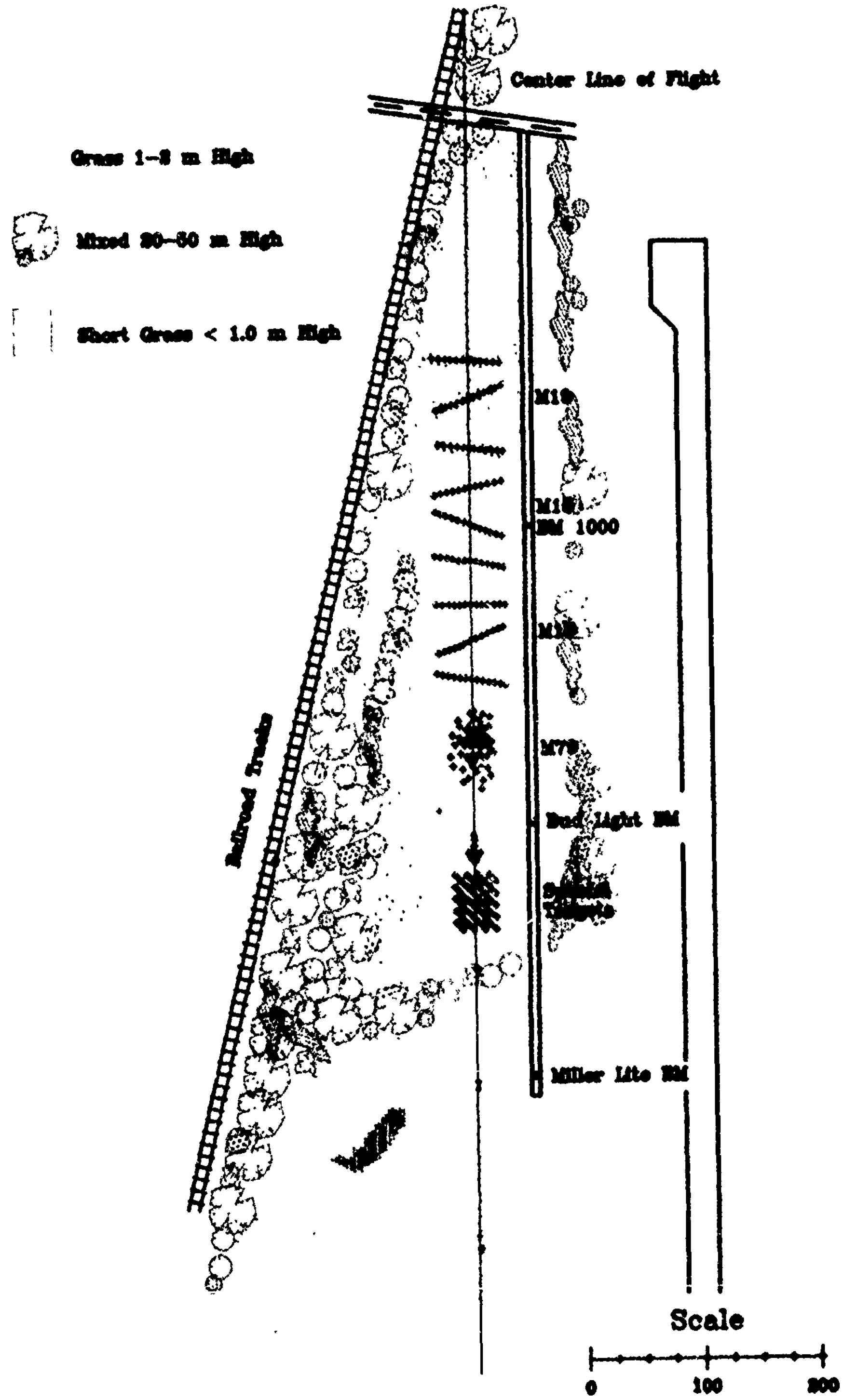


Figure 21. Drawing of Site A showing prepared target areas

plots continuing along width of trail (northward), saw briers, *Polyganum* sp. Path is mostly dead brier material.

12. Treeline turns and heads north. Cottonwood, Johnson grass, saw briers, *Polyganum* sp.

13. Treeline along railroad tracks, then break in (linear) treeline, Johnson grass, goldenrod on front.

Meteorology

40. A freeze occurred on the night of 19 October 1989. A brief visit the following morning revealed no damage; however, a considerable warming occurred in subsequent days, resulting in a wilting of the green plant parts. A fall condition (leaf color change, leaf fall, etc.) had been progressing slowly since activity began at the site earlier in the month; the freeze accelerated the process. Since this exercise was scheduled to last 2 weeks, this senescence became quite readily apparent before the end of the exercise. This vegetation change could have influenced background "signature" in the REMIDS images obtained in this exercise.

41. Plots of meteorological parameters data acquired during the periods within which REMIDS overflights were conducted are found in Figure 22.

42. Thermal records of the backgrounds (five) and target types (three) were initiated at about 1600 hr on 16 October 1989 and continued (with some interruptions) until 2 November 1989. These data are displayed in Figure 23.

Target areas

43. There were five distinct target areas located in site A, the grassy field. From south to north the specially prepared plots were laid out as shown in Figure 21. The first target area is described as follows: five strips were each prepared to present a different background to the sensor (Figure 24). Beginning at the south of the specially prepared strips there were (a) a 5-m by 10-m strip left as high grass; (b) the next strip cut to a height of about 0.5 m; (c) the next strip mowed close to the surface; (d) the next strip plowed and left in regular furrows at right angles to the proposed flight line; and (e) the last strip plowed flat with no obvious furrows. The four target sets, each composed of the principal US mine types (M15, RAAM (M75), and M19) arranged at about a 45-deg angle from the proposed flight path, were essentially equidistantly placed across each strip (Figure 24). Each strip was situated at right angles to the nominal flight line.

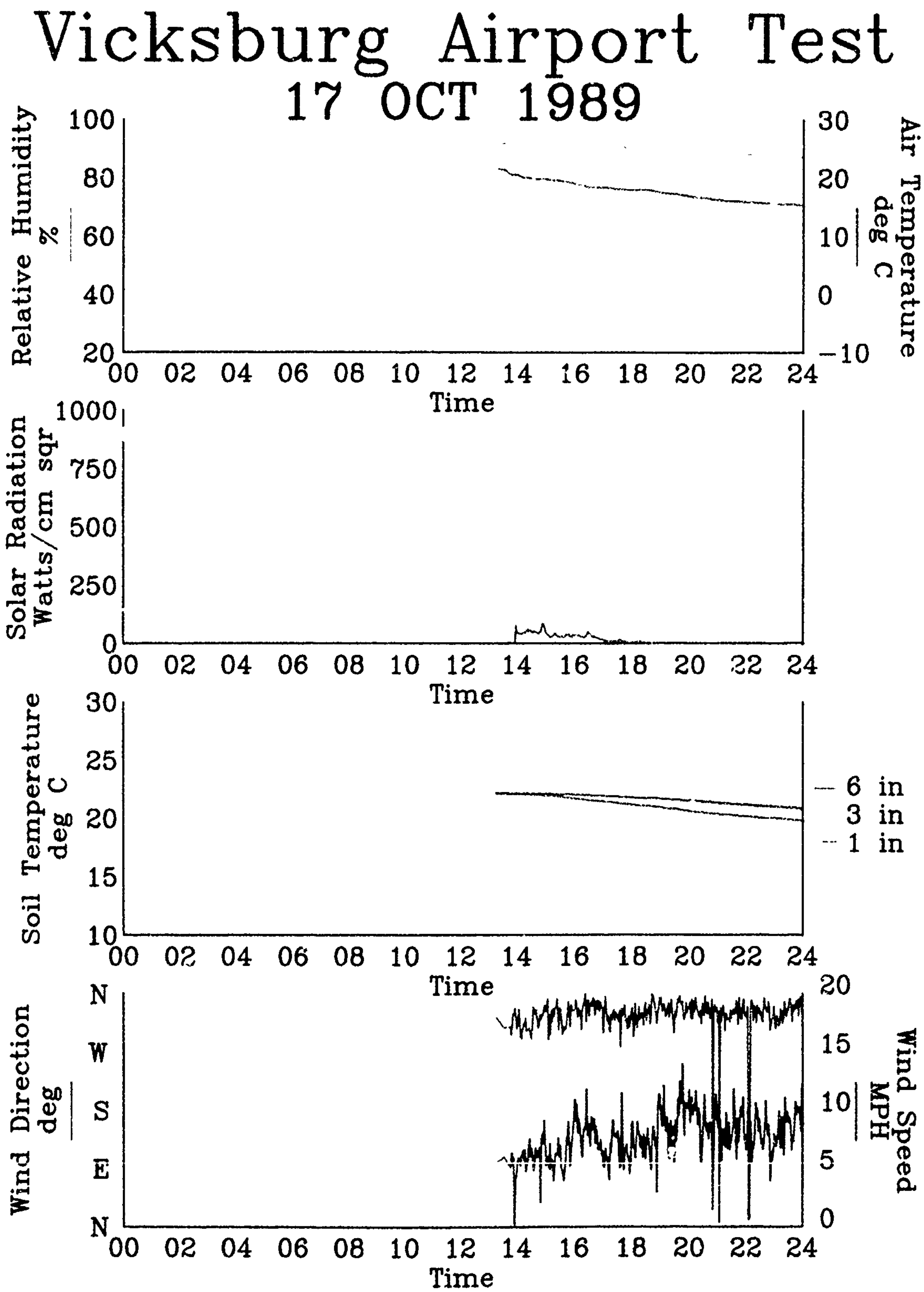


Figure 22. An example of October 1989 meteorological record

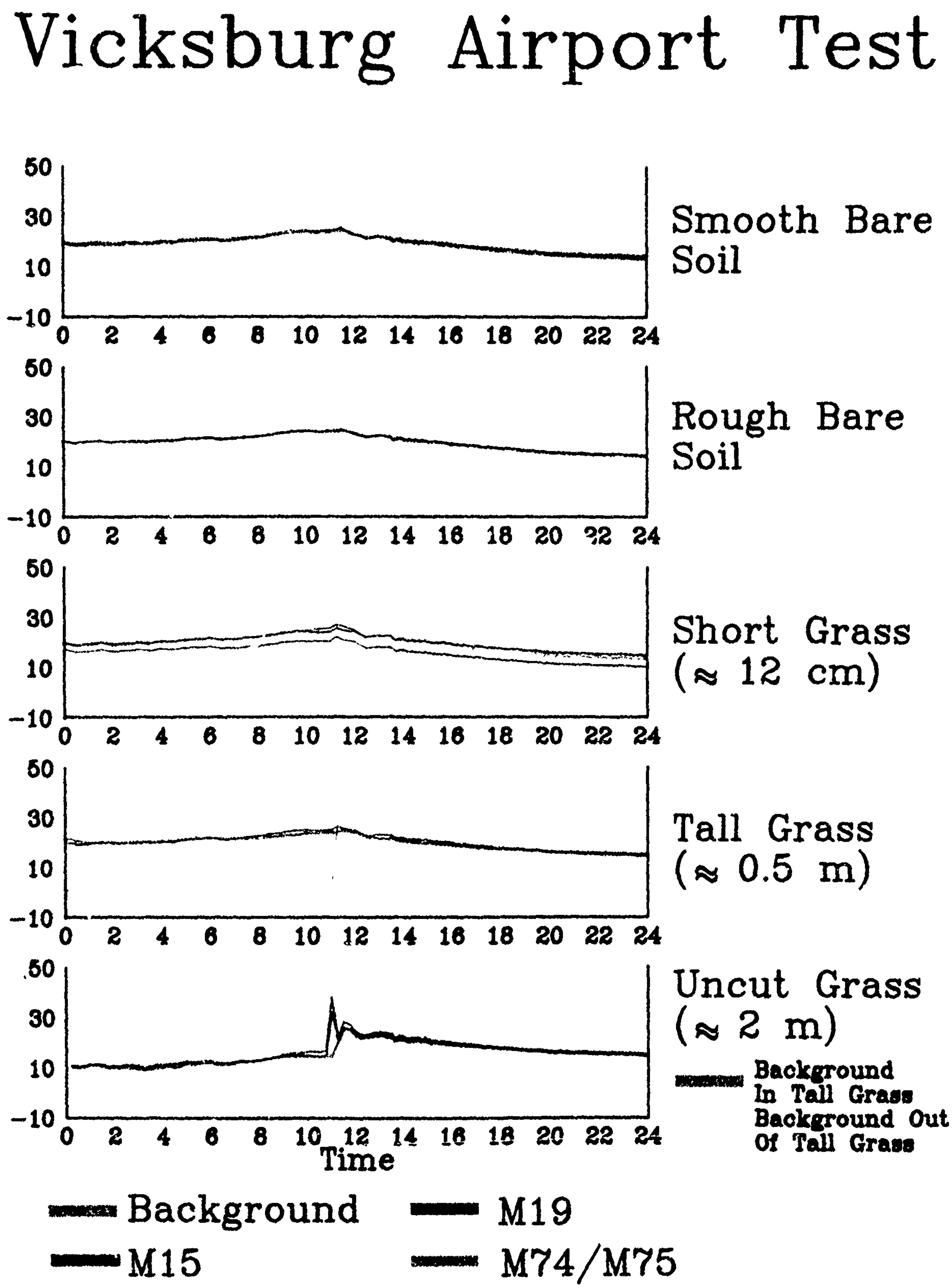


Figure 23. Example of thermal record of October 1989 test period

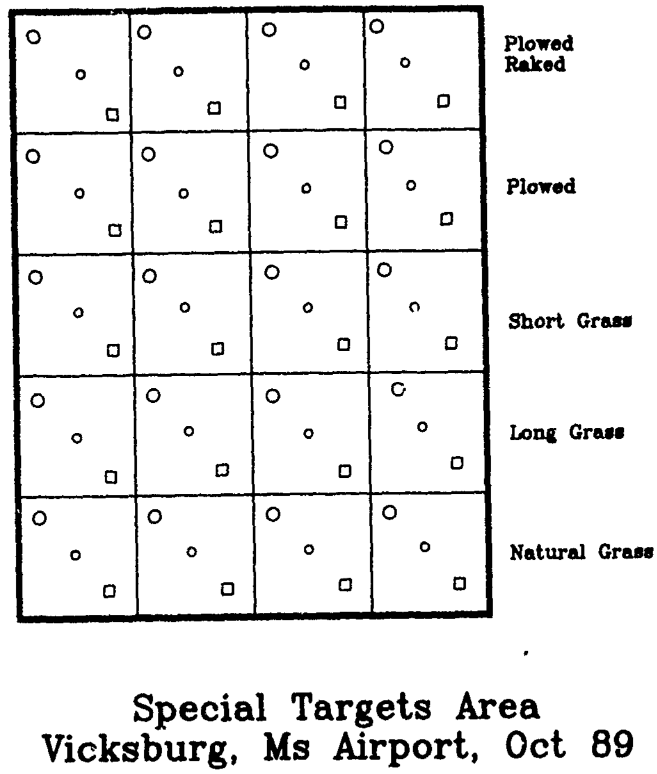


Figure 24. October 1989 special target areas

44. A second target area (Figure 25) containing the calibration targets was placed immediately north of the first target area

45. A third target area with 54 "randomly" emplaced RAAM's (M75) (Figure 26) was placed within a 40- by 70-m area arranged with longer side parallel to the nominal flight line down the middle of the width of the M75 target area.

46. The fourth and fifth target areas were oblique lines of M15's bisected by the flight line (Figure 27). The sixth area contained M19's arranged in like fashion in "virgin" (not recently mowed) high grass (Figure 28).

ARPI data

47. ARPI data collected in November after the October overflights included those shown in Table 6, with measurements of polarization responses being taken for a variety of both artificial and "natural" targets. Figure 29 shows relative polarization values obtained when selected targets were measured: the relationships of measurements made at different times of the year of similar targets is shown in Figure 30. No significant correlation was found between the two different measurement times.

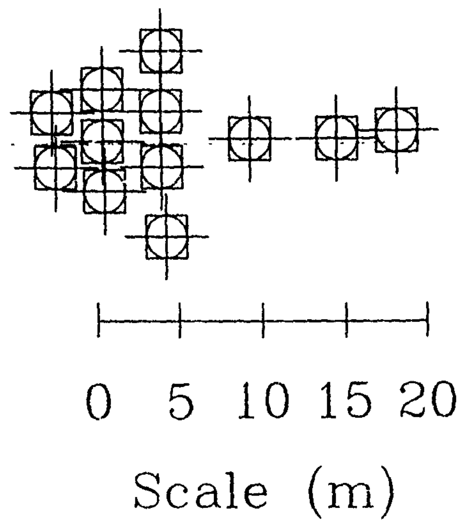


Figure 25. October calibration targets

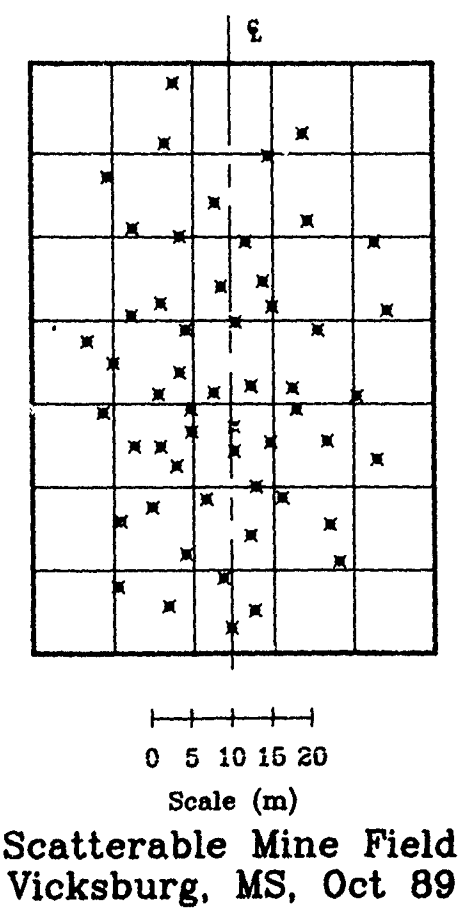
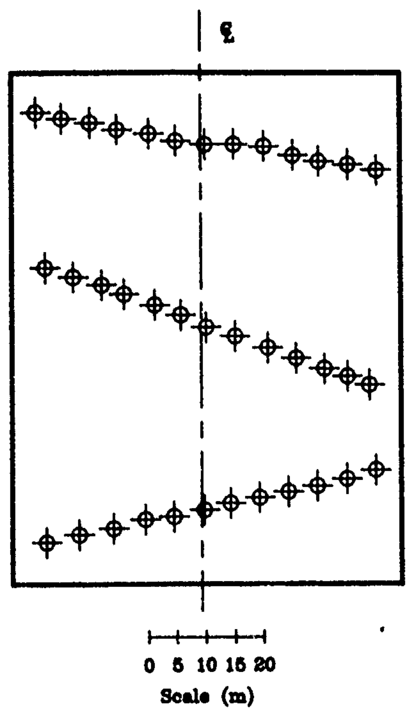
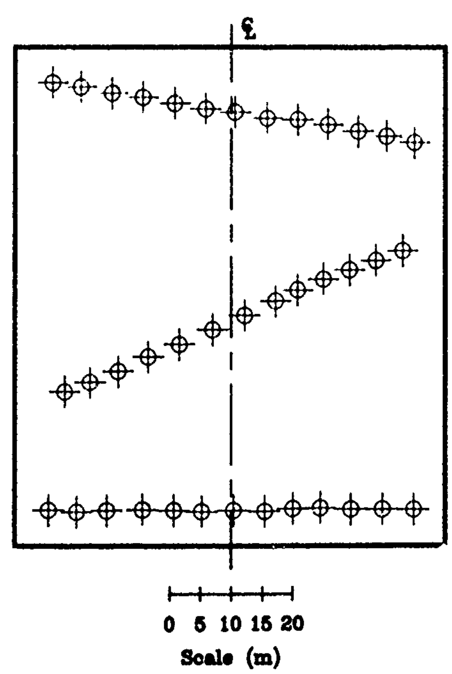


Figure 26. October RAAM (M75) target area



Minefield - M-15 - #1
Vicksburg, Ms, Oct 89



Minefield - M-15 - #2
Vicksburg, Ms, Oct 89

Figure 27. October M15 target areas

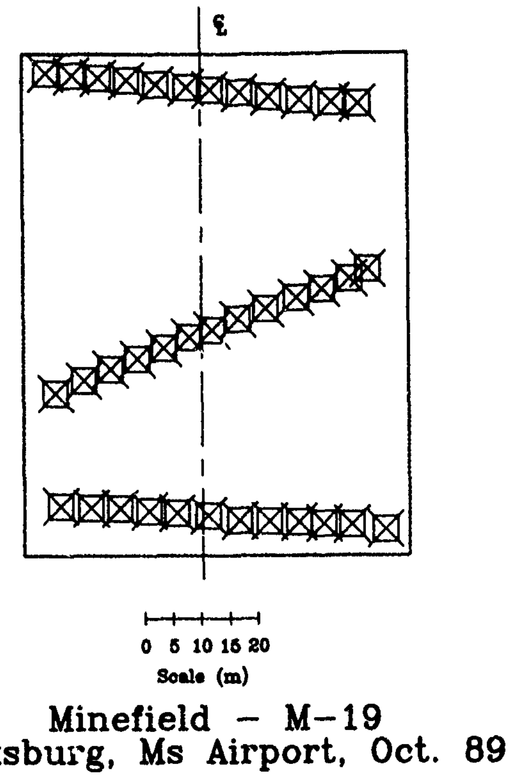


Figure 28. M19 target area

48. The mines were retrieved on or about 2 November 1989 after all the REMIDS missions had been flown.

Table 6

Mean Raw Image Values Acquired on 24 October 1989

Polarization Returns, Backgrounds		Thermal	Polarization Returns, Targets	
Flat, bare soil			88G1*	
Maximum	139	61	Maximum	255**
Minimum	75	0	Minimum	87
Mean	109	30	Mean	174
Sigma	5	10	Sigma	66
Furrowed bare soil			88FU	
Maximum	134	76	Maximum	225
Minimum	78	0	Minimum	112
Mean	113	40	Mean	174
Sigma	7	12	Sigma	55
Low-mown grass			88FL	
Maximum	132	52	Maximum	255**
Minimum	68	0	Minimum	109
Mean	100	15	Mean	176
Sigma	7	10	Sigma	58
Medium-mown grass			WEG1	
Maximum	145	47	Maximum	195
Minimum	66	0	Minimum	97
Mean	104	8	Mean	141
Sigma	8	8	Sigma	27
High-mown grass			WEFU	
Maximum	165	50	Maximum	177
Minimum	65	0	Minimum	89
Mean	104	14	Mean	140
Sigma	7	10	Sigma	30
			WEFL	
			Maximum	188
			Minimum	103
			Mean	139
			Sigma	26

* Target code definitions will be furnished to qualified requesters.
** Saturated.

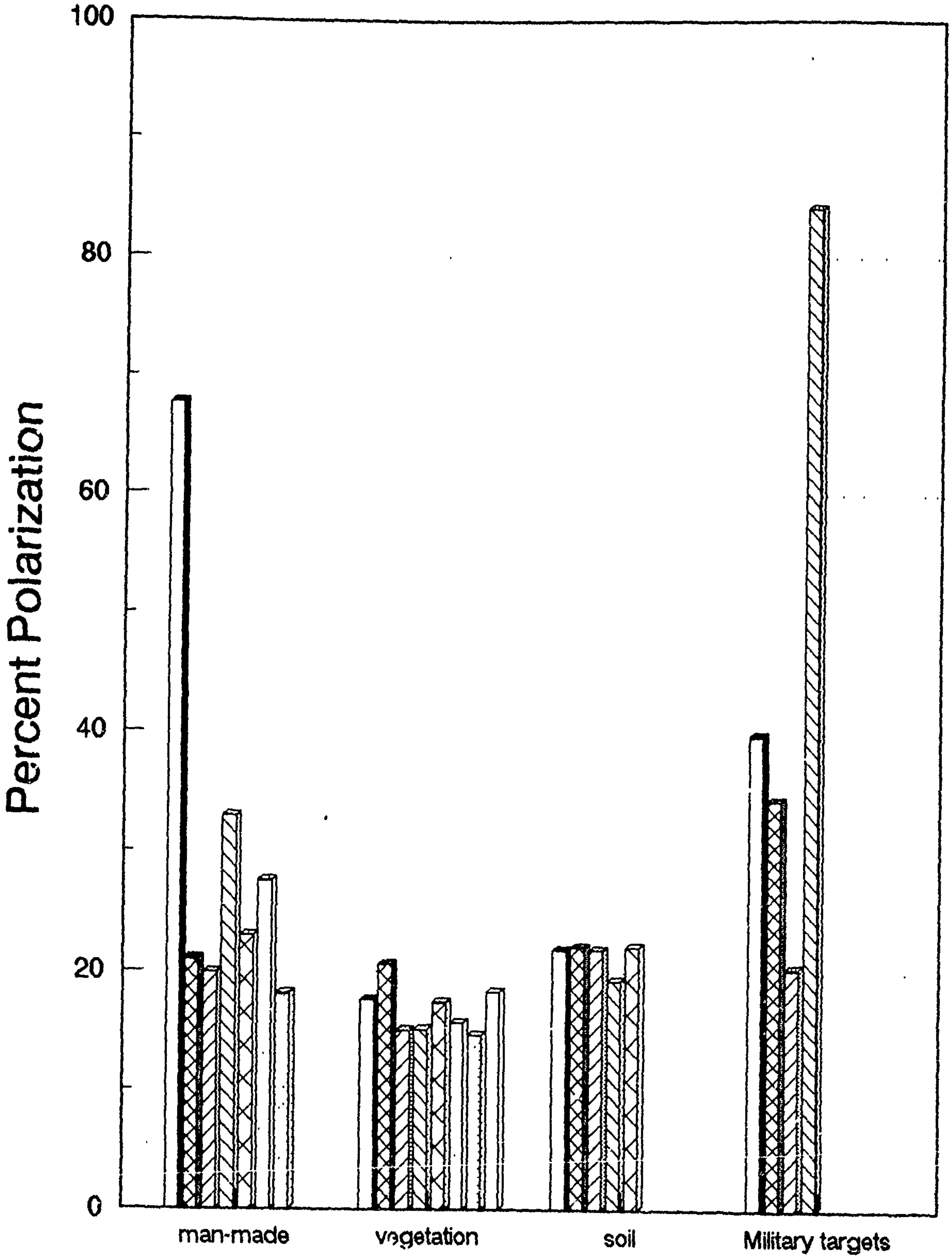


Figure 29. November ARPI measurements

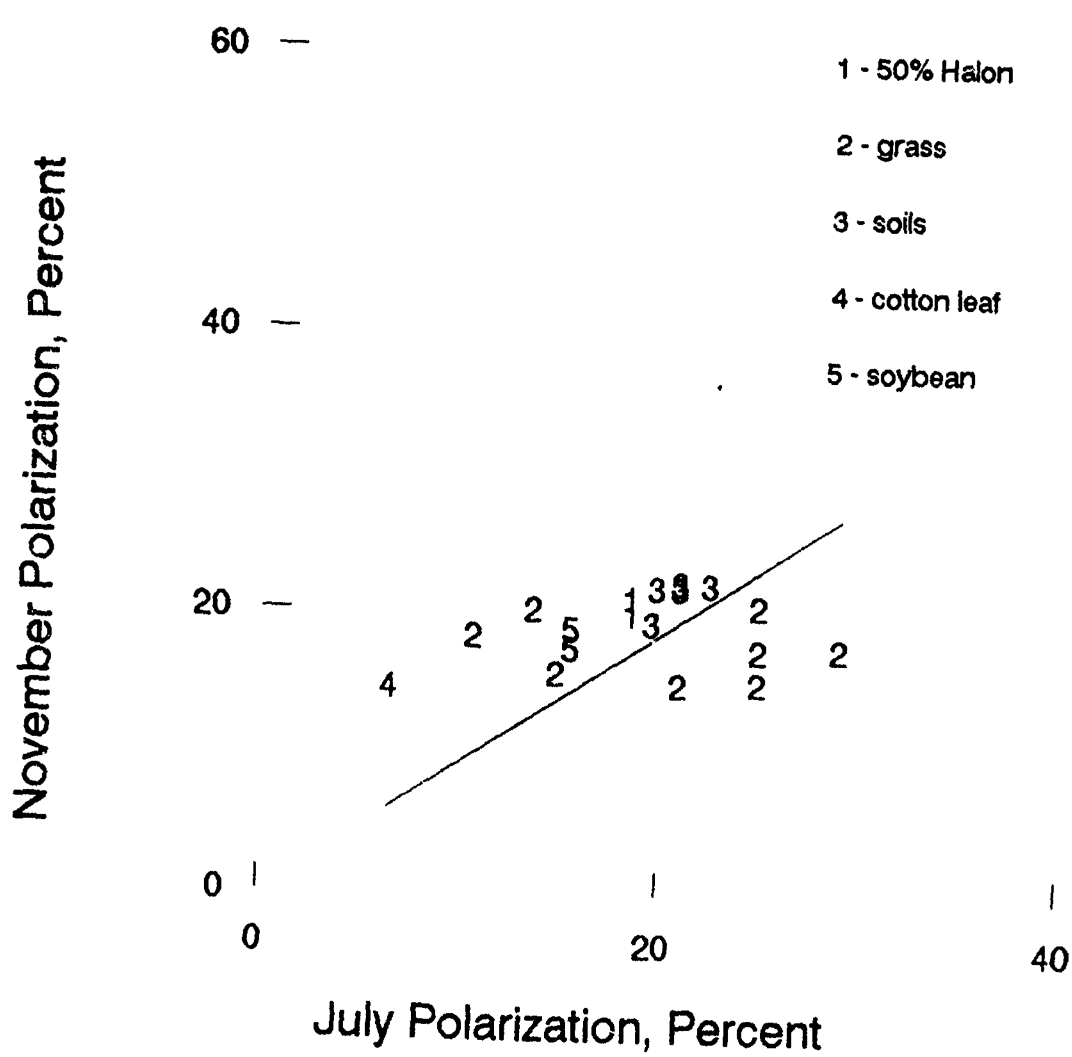


Figure 30. Time-of-year effects on polarization response

PART IV: SUMMARY AND DISCUSSION

49. These field tests were designed to provide quantitative data with which to compare corresponding REMIDS data and so evaluate the performance of the REMIDS sensor against a variety of backgrounds under summer and early fall conditions in a southeastern US locale. These data can be used to assess REMIDS efficiency in discriminating targets from their backgrounds in areas having similar vegetation and soil conditions as tested.

50. In the Vicksburg Municipal Airport exercises of 1989, summer and fall, the site design and documentation method employed were demonstrated as viable and adequate to be applied to more ambitious tests of longer duration and greater data volume as well as more varied environmental conditions. Moreover, automated data collection and display techniques enabled a timely production of results, implying that preliminary performance and maturity ratings of the sensors' technology may soon be available. The site characterization and target layout for the two REMIDS Vicksburg Airport tests were sufficient for the intent of the exercise, since the attendant measurements will allow comparison of "raw" sensor data, after being calibrated and standardized by WES algorithms, to be co-registered and compared with corresponding targets, backgrounds, and calibration targets.

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APPENDIX A: SOIL ANALYSIS PROCEDURES

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Description of Laboratory Soil Analysis

Specific gravity

1. This is the ratio of the weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. Specific gravity is sampled as bulk surficial soil.

Grain-size distribution

2. This is a descriptive measure of the soil particle size classes. It delineates percentages of soil particle sizes by successive sieving using sieves decreasing in size to mesh No. 200 (0.074 mm). Smaller sizes are analyzed in a hydrometer to approximately 0.001-mm diam. As shown in Figure A1, a sample soil gradation sheet, a bar below the x-axis shows the soil classification corresponding to certain grain sizes. The left y-axis shows the percent finer by weight passing the sieve size. The right y-axis shows the percent coarser by weight retained by the sieve size. The x-axis is the particle size in millimetres.

Soil texture and color

3. After conducting a detailed analysis, the US Army Engineer Waterways Experiment Station (WES) Soils Testing Laboratory assigns a soil classification based on the Unified Soil Classification System (USCS) and the US Department of Agriculture and located on each individual soil gradation analysis sheet. A detailed explanation of the USCS is given in Technical Memorandum No. 3-357 (USAEWES 1960).*

Atterberg limits

4. Atterberg limits represent the following three plasticity stages that are a function of moisture ranges. Data on Atterberg limits are included on the bottom of the soil gradation analysis sheets.

- a. Liquid limit. Defines the upper plastic range of a soil.
- b. Plastic limit. Defines the lower limit of the plastic range of a soil.
- c. Plasticity index. The difference between the liquid limit and the plastic limit.

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* See References at the end of the main text.

Organic content

5. The living or previously living fraction of the soil. This test defines the organic fraction as that amount of mass lost on ignition during exposure to 550° C.

Cone Index

6. Soil strength was determined by consistently forcing at a constant rate of penetration of a standard-sized 0.2-in.-area cone through the .pa soil to a specified depth. The force required for penetration is indicated by the displacement on a micrometer gage and is read at the surface and at 2.5-cm-depth intervals. Additional information detailing the cone penetrometer and use can be found in Army TM 5-530 (US Army Corps of Engineers 1971).

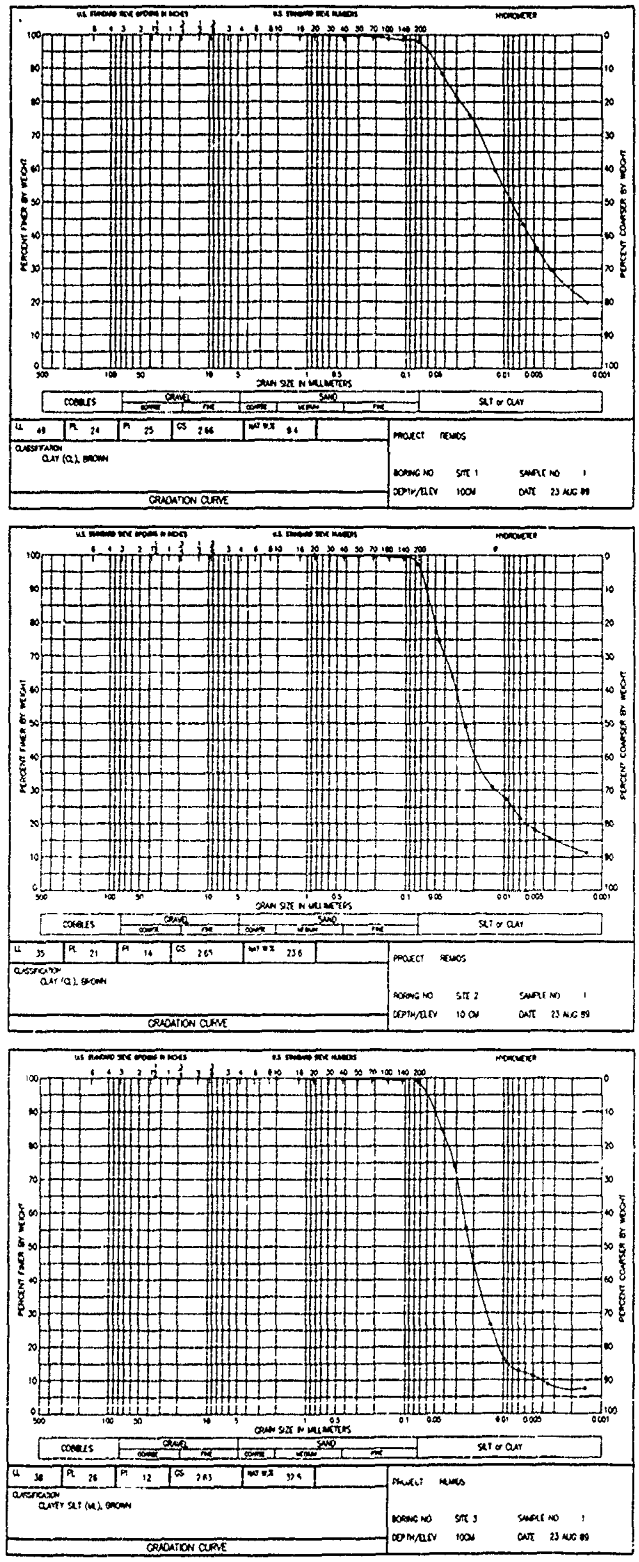


Figure A1. Soil gradation sheet

APPENDIX B: ACTIVE REFLECTOMETER POLARIZATION INSTRUMENT (ARPI)

APPENDIX B: ACTIVE REFLECTOMETER POLARIZATION INSTRUMENT (ARPI)

1. The Active Reflectometer Polarization Instrument (ARPI) was constructed as a support instrument for the Remote Minefield Detection System. The active component consists of a solid state polarized neodymium:yittrium aluminum garnet (Nd:YAG) laser with an output power of approximately 50 mw per square centimeter. The laser beam is sent through a set of lenses to achieve a divergence of 1 deg and then is reflected off a coated mirror, passed through a dichroic, to allow for optical alignment through the viewfinder, reflected off an elliptical mirror, passed out through the receiving lens, and reflected downward by an external mirror toward the target surface. A pair of detectors with matched and calibrated responses are controlled by a United Detector Technology (UDT) S380 radiometer unit fitted with an Institute of Electrical and Electronic Engineers (IEEE)-488 computer interface. Backscattered return must pass through the 2-in. receiving lens with a 3-deg field of view, a polarizing beam-splitting cube, and then a 1,064-nm line filter before reaching the active area of the detectors. A photograph of ARPI is included as Figure B1.

Balancing the Channels

2. When a field of unpolarized radiance (e.g., a sunlit diffusing surface) is viewed, the output from the two channels should be identical, but probably will not be. There will always be small differences in reflectivity and transmission of the optics that can add up to a few percent difference in the outputs of the two channels. The method used to balance the two channels takes advantage of the wavelength calibration provided in the instrument.

3. The two detectors have been factory calibrated in absolute terms for every 10 nm of wavelength. These calibration data are stored in the removable electrically programmable read only memory (EPROM) in the unit, and when called upon, set the channel gain so that the output reading gives absolute radiometric data. Since we are interested only in relative data, false wavelength settings can be input so as to make small gain adjustments in one or both channels until balance is achieved. Additional "fine tuning" can be accomplished by reducing the wavelength for channel 1 by 10 or 20 nm.

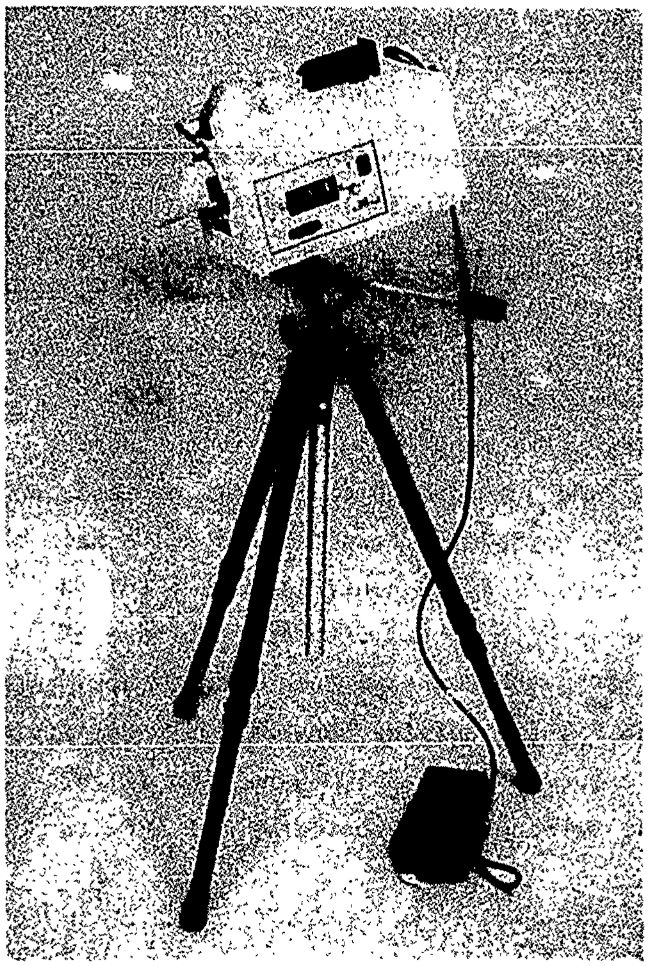


Figure B1. Photograph of ARPI

Focusing

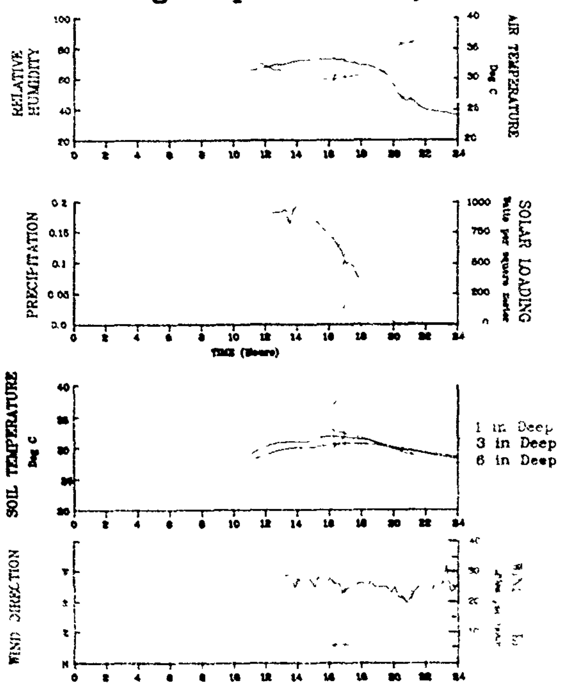
4. The instrument can be focused for any distance from 60 to 120 in. The viewfinder and radiometer channels are parfocalized so that when the viewfinder is visually in focus, so is the radiometer.

Field of View

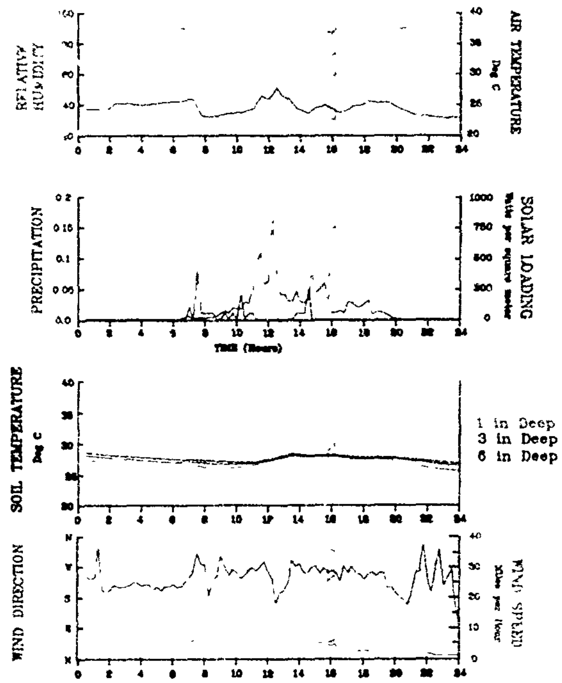
5. The radiometer measures all 1,064-nm radiation within a 2-deg field of view centered on the optical axis and is described by the outer circle in the viewfinder reticle. The outgoing laser beam angle is approximately 1 deg in diameter and is described by the inner circle in the viewfinder reticle. The total visual field of view through the viewfinder is approximately 6 deg.

APPENDIX C: METEOROLOGICAL AND THERMAL RECORDS, JULY 1989

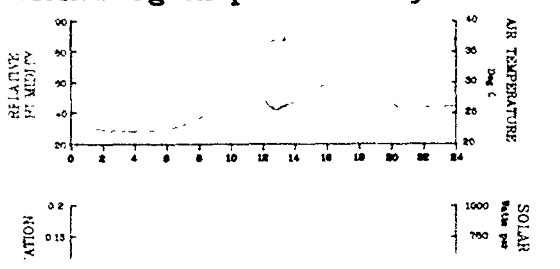
ENVIRONMENTAL SUMMARY
Vicksburg Airport 12 July 1989



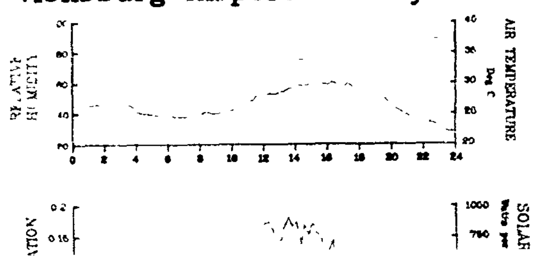
ENVIRONMENTAL SUMMARY
Vicksburg Airport 13 July 1989

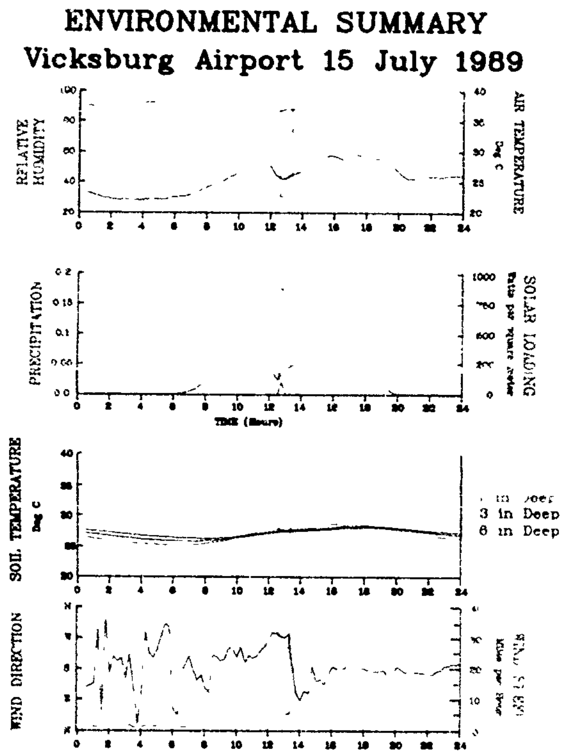


ENVIRONMENTAL SUMMARY
Vicksburg Airport 15 July 1989



ENVIRONMENTAL SUMMARY
Vicksburg Airport 16 July 1989





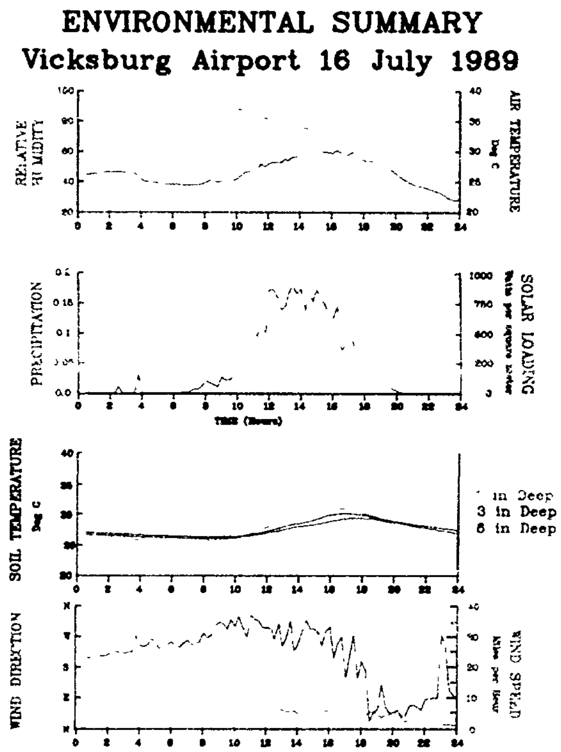
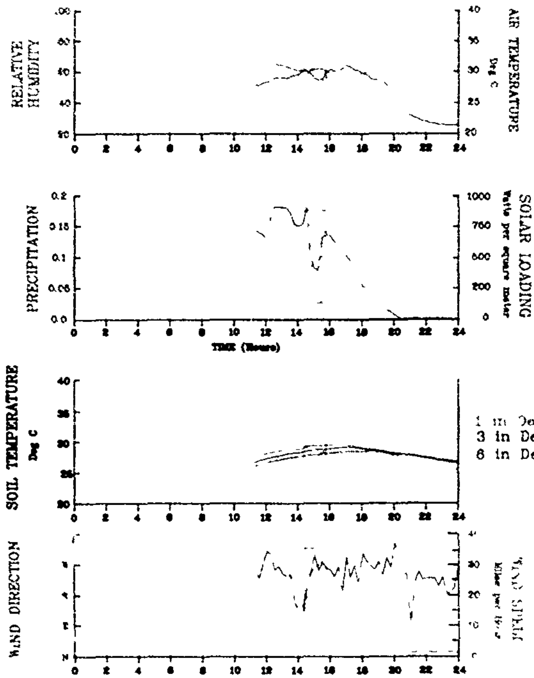
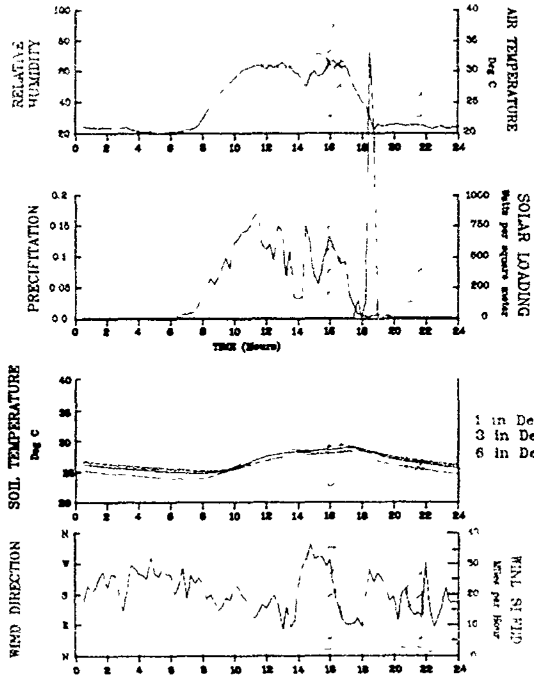


Figure C1. Sample meteorological records of test period beginning on 12 July 1989 (Continued)

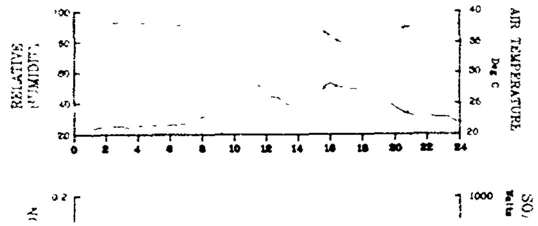
ENVIRONMENTAL SUMMARY
Vicksburg Airport 21 July 1989



ENVIRONMENTAL SUMMARY
Vicksburg Airport 22 July 1989



ENVIRONMENTAL SUMMARY
Vicksburg Airport 24 July 1989



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Vicksburg Airport 24 July 1989

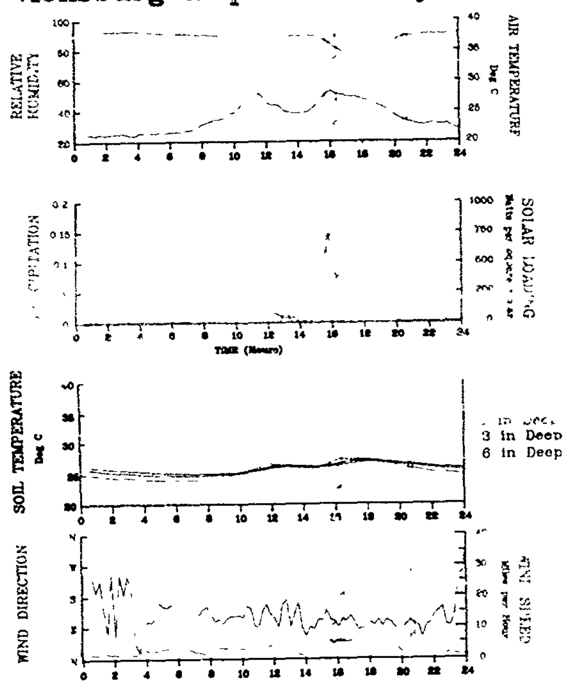
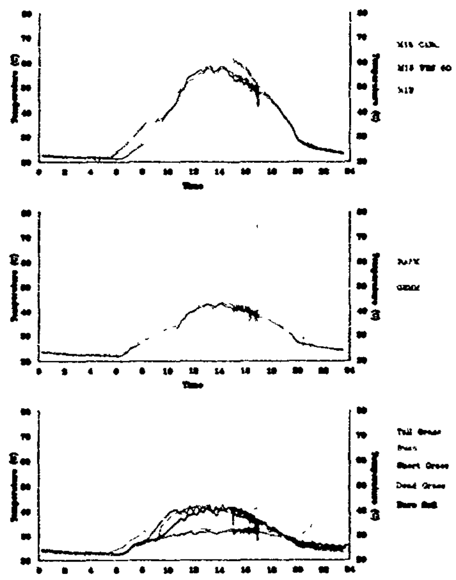


Figure C1. (Concluded)

Thermal Data
Vicksburg Airport 12 July 1989



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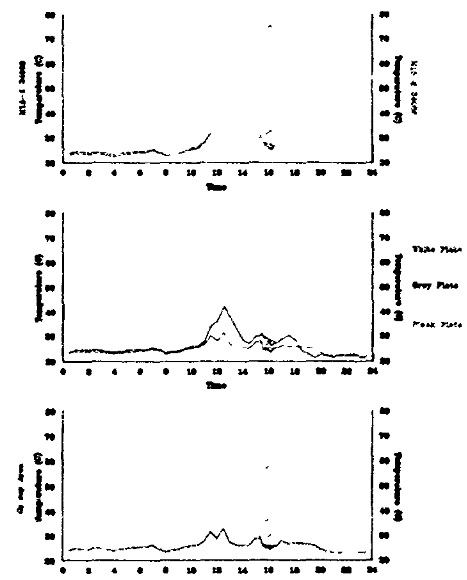

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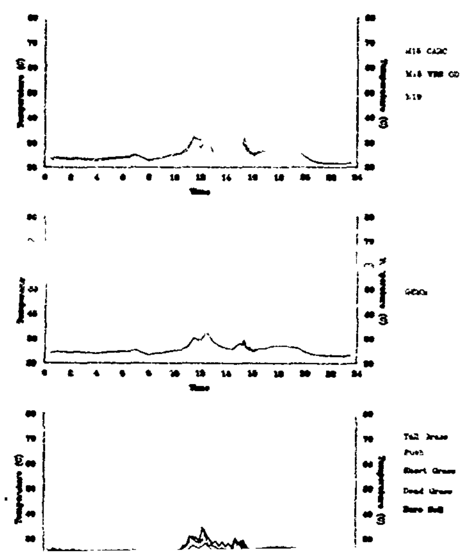

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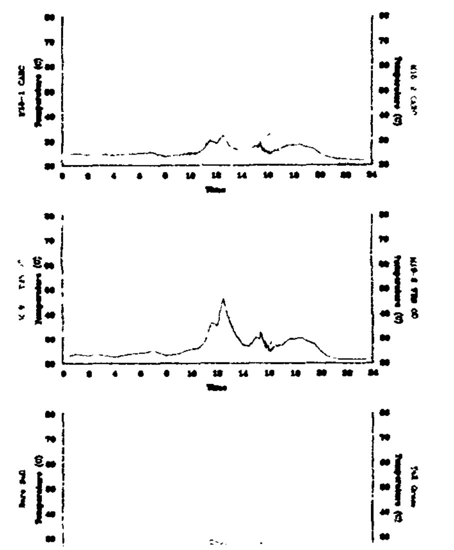

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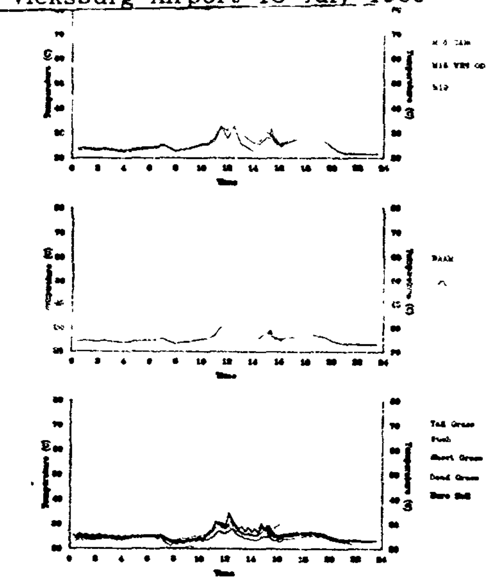

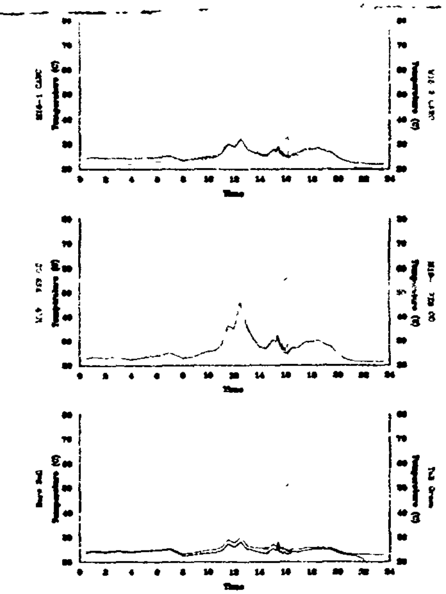

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Vicksburg Airport 13 July 1989

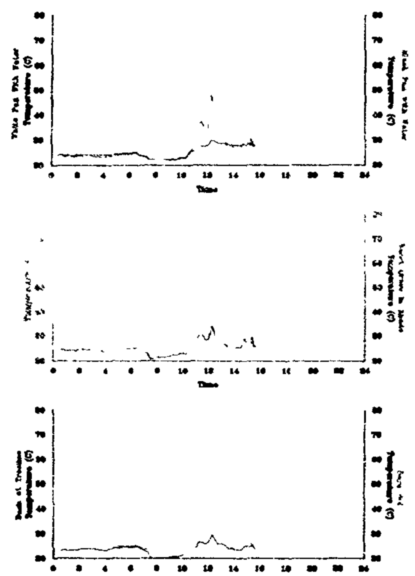
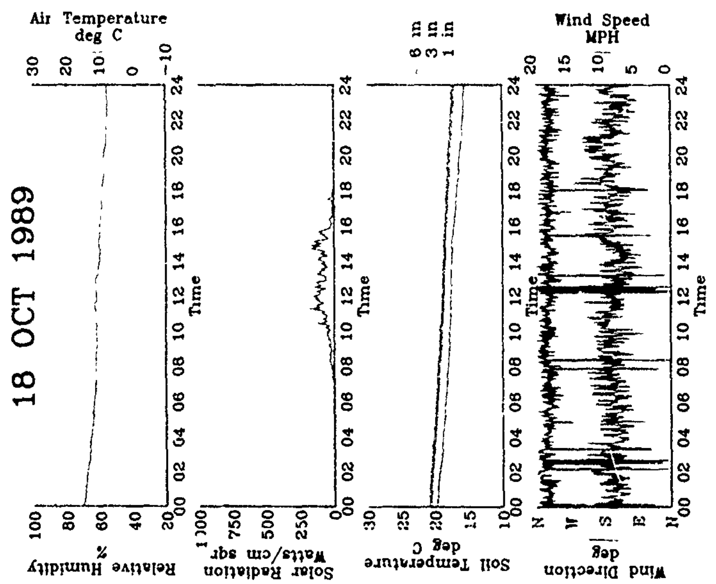
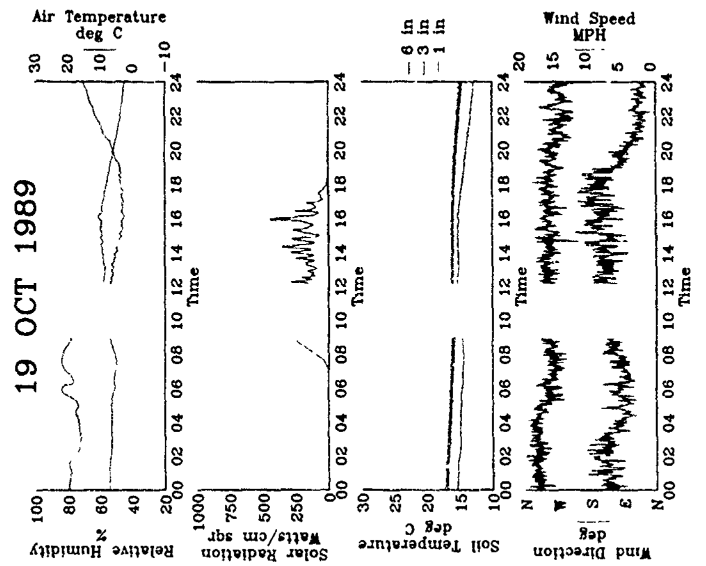
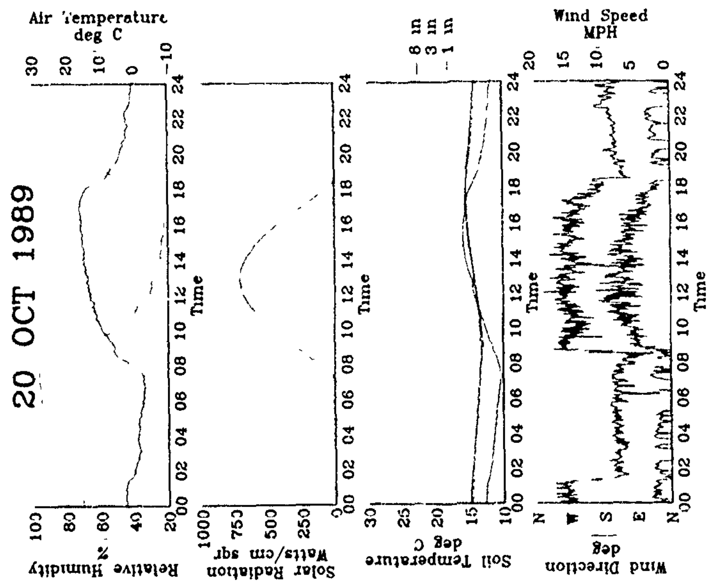


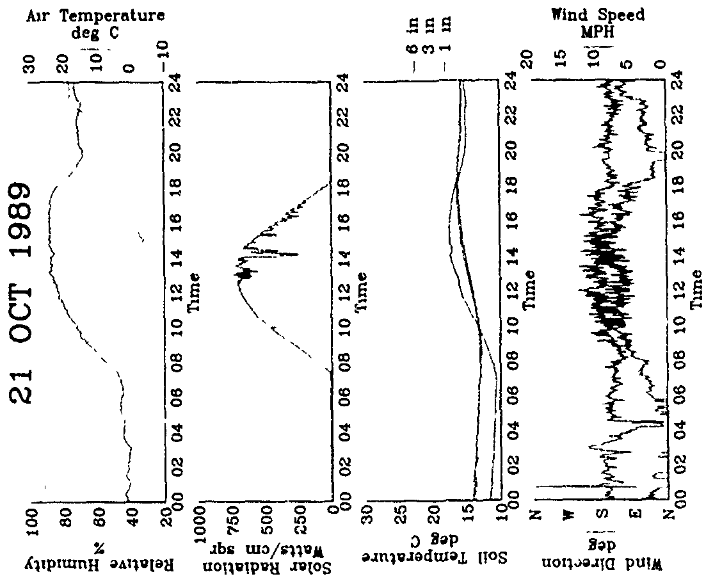
Figure C2. Sample thermal records of test period beginning on 12 July 1989

APPENDIX D: METEOROLOGICAL AND THERMAL RECORDS, OCTOBER 1989


18 OCT 1989
Air Temperature
deg C
Relative Humidity
%
Solar Radiation
Watts/cm sqr
Soil Temperature
deg C
6 in
3 in
1 in
Wind Speed
MPH
Wind Direction
deg
Time


19 OCT 1989
Air Temperature
deg C
Relative Humidity
%
Solar Radiation
Watts/cm sqr
Soil Temperature
deg C
6 in
3 in
1 in
Wind Speed
MPH
Wind Direction
deg
Time


20 OCT 1989
Air Temperature
deg C
Relative Humidity
%
Solar Radiation
Watts/cm sqr
Soil Temperature
deg C
6 in
3 in
1 in
Wind Speed
MPH
Wind Direction
deg
Time


21 OCT 1989
Air Temperature
deg C
Relative Humidity
%
Solar Radiation
Watts/cm sqr
Soil Temperature
deg C
6 in
3 in
1 in
Wind Speed
MPH
Wind Direction
deg
Time

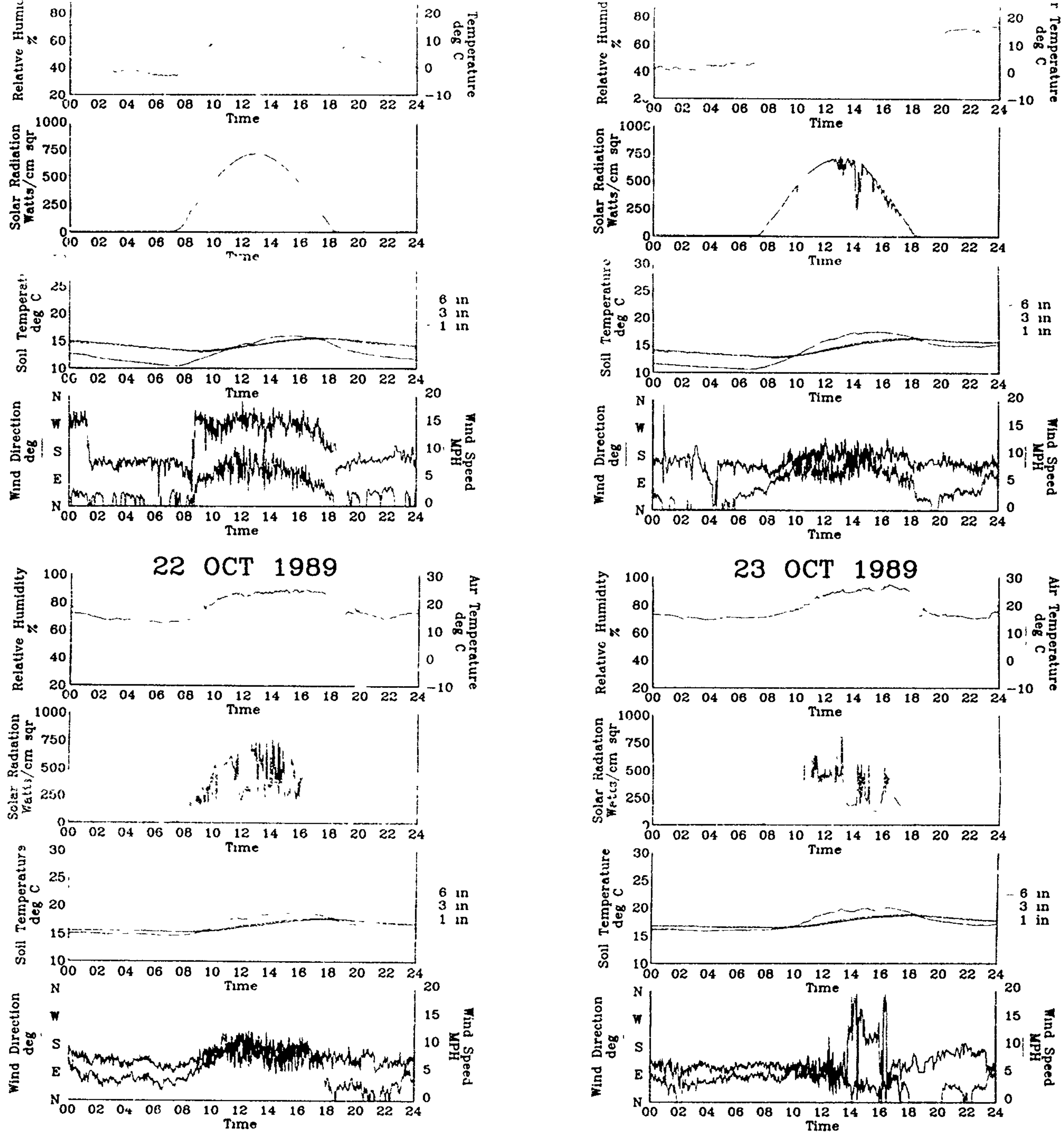
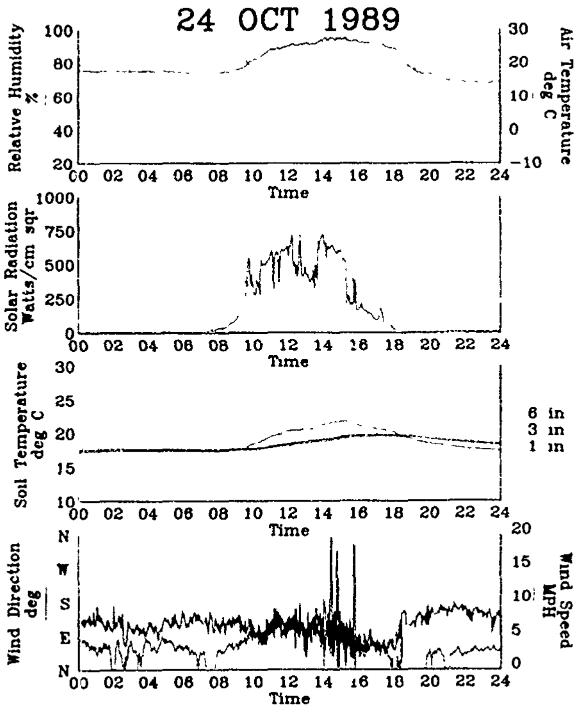
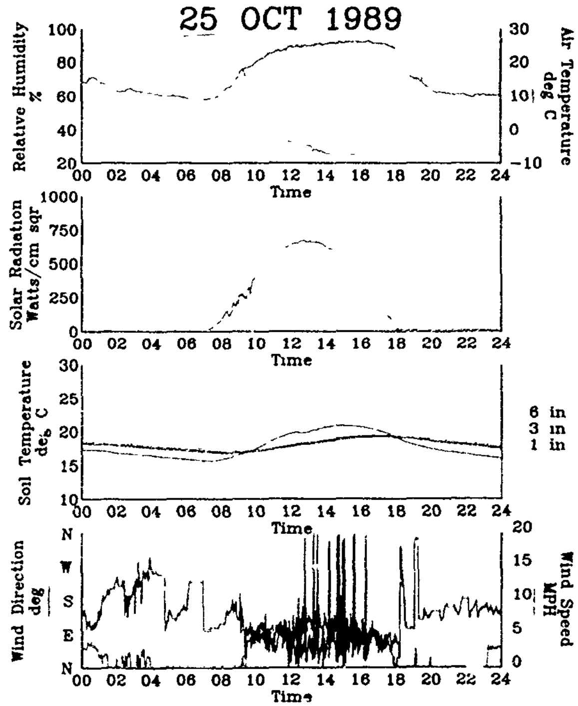
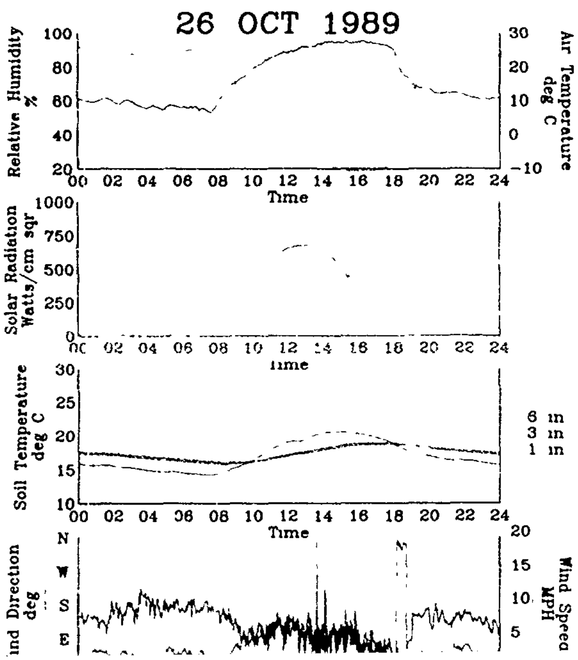
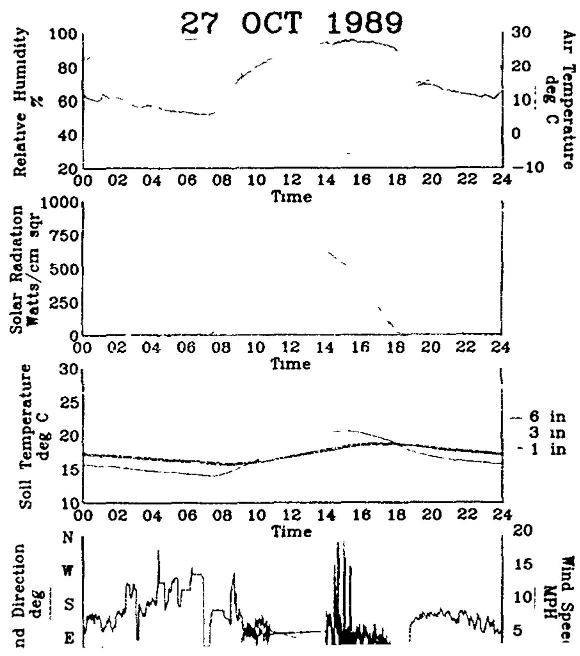


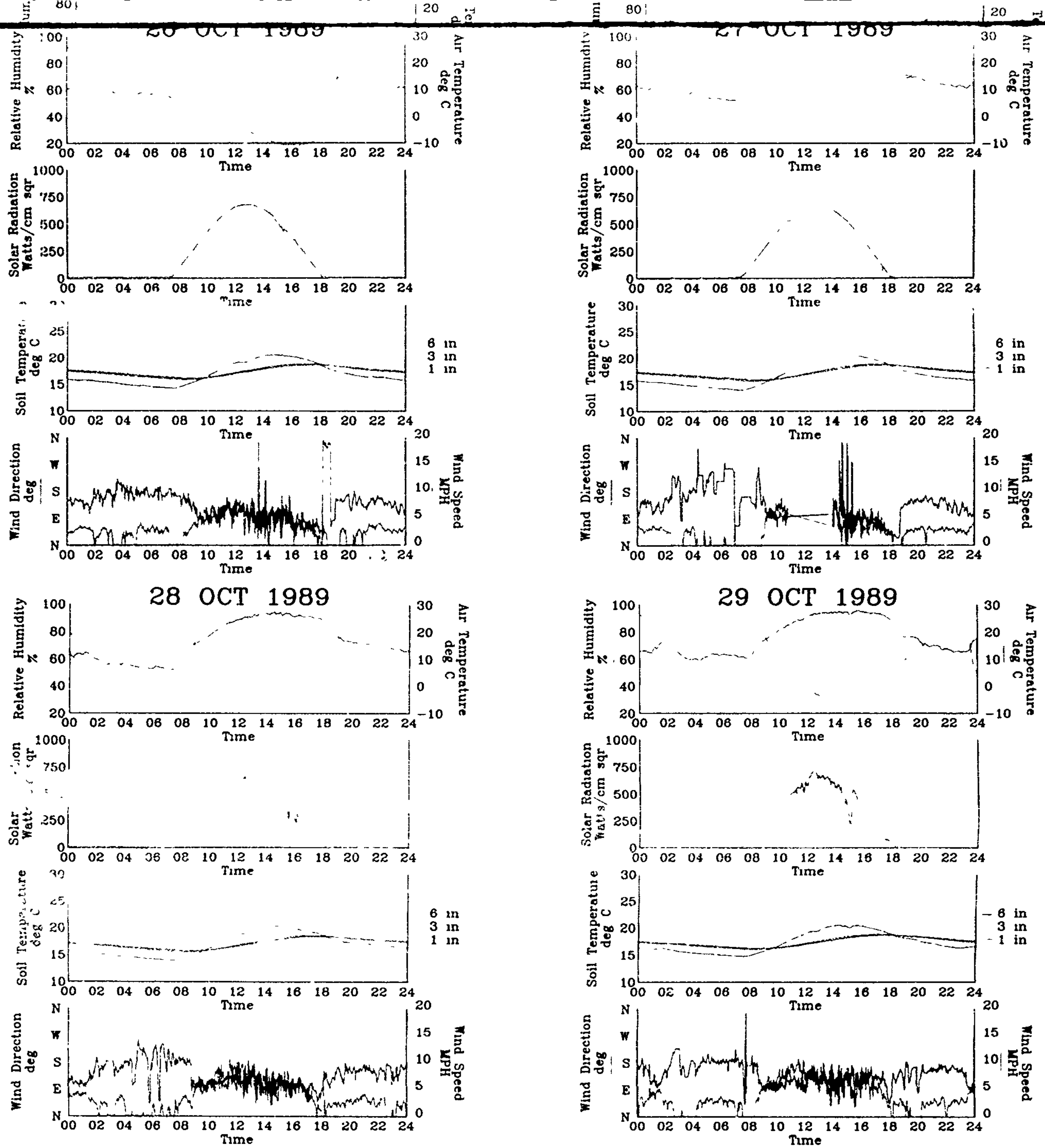
Figure D1. October 1989 meteorological records (Sheet 1 of 3)


24 OCT 1989
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Wind Direction deg
Wind Speed MPH
Time


25 OCT 1989
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Wind Direction deg
Wind Speed MPH
Time


26 OCT 1989
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Time


27 OCT 1989
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Time



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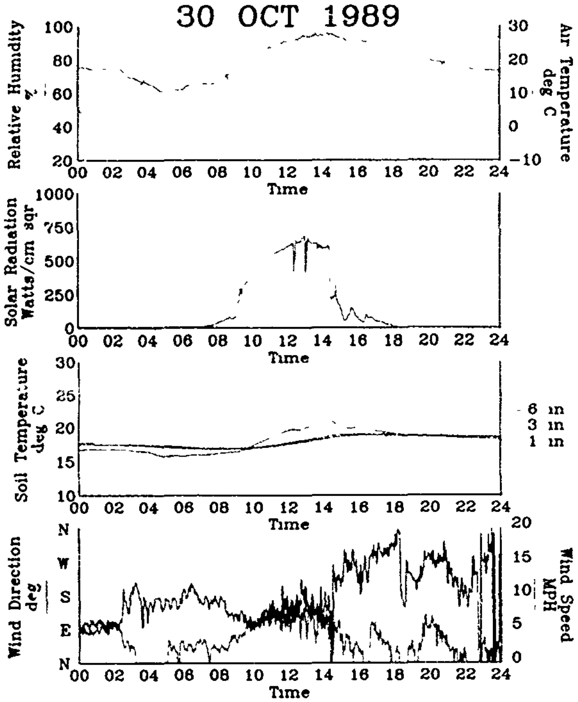
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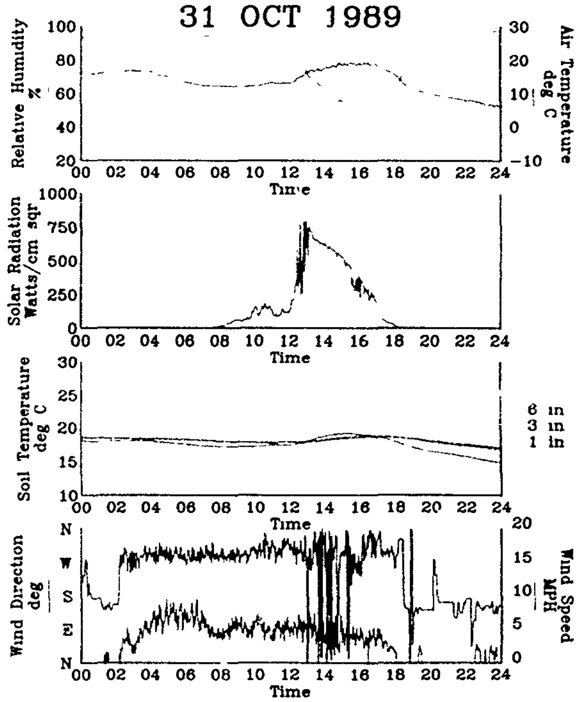
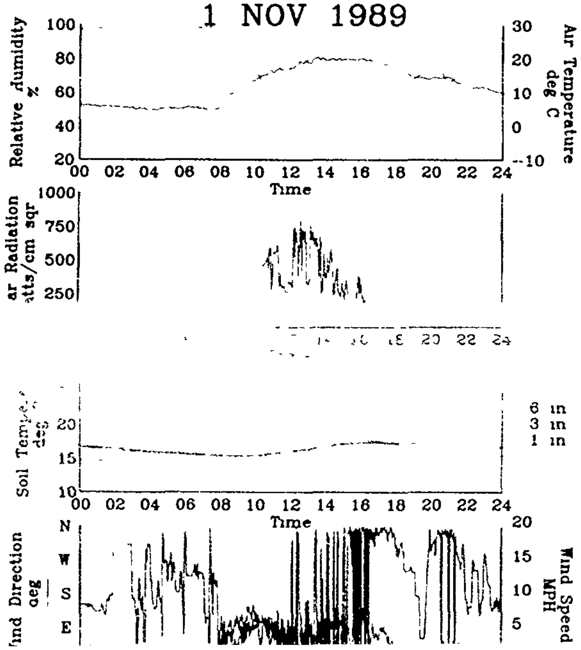
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Wind Direction deg
Wind Speed MPH
Time


31 OCT 1989
Relative Humidity %
Air Temperature deg C
Solar Radiation Watts/cm sqr
Soil Temperature deg C
6 in
3 in
1 in
Wind Direction deg
Wind Speed MPH
Time


1 NOV 1989
Air Temperature deg C
Wind Speed MPH
Time

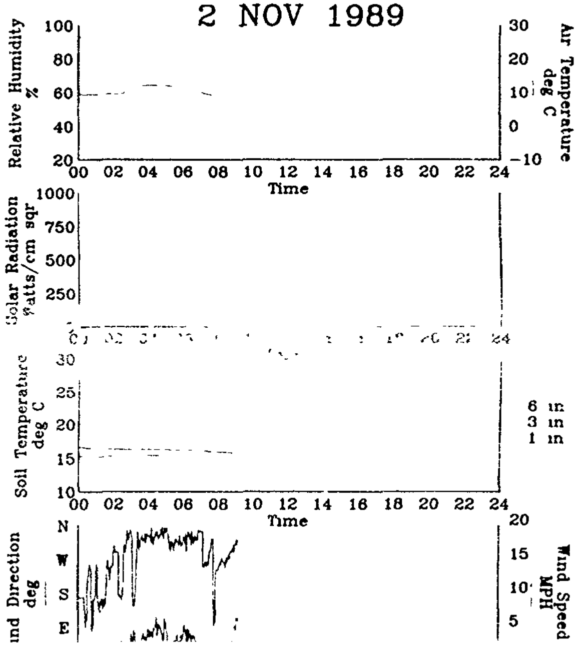
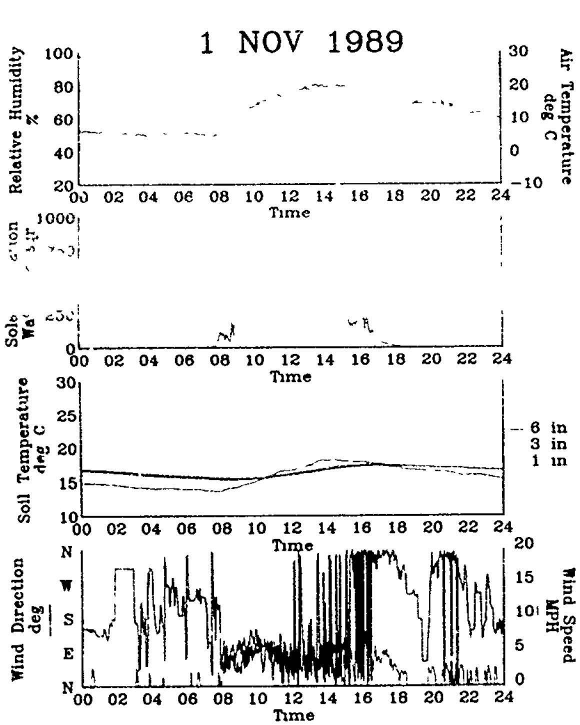

2 NOV 1989
Relative Humidity %
Air Temperature deg C
Soil Temperature deg C
6 in
3 in
1 in
Wind Speed MPH
Time

Figure D1. (Sheet 3 of 3)



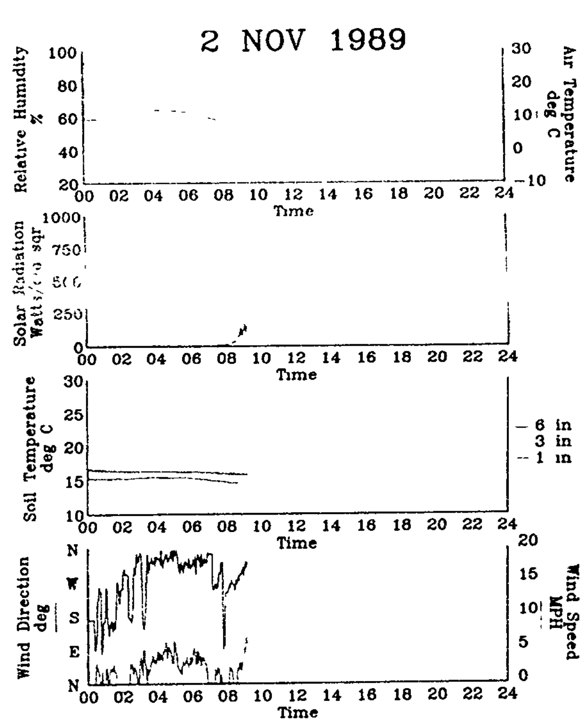
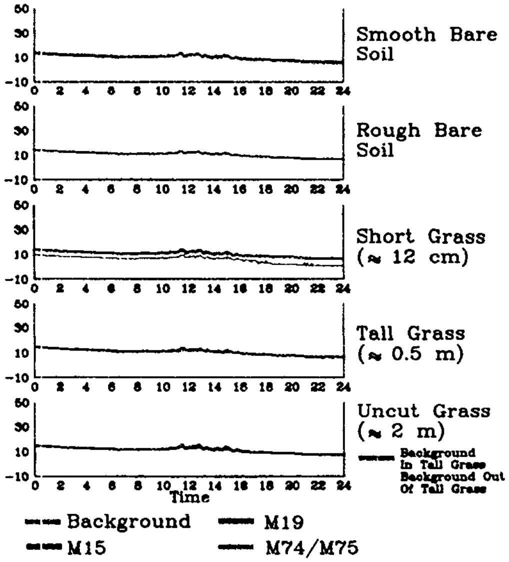
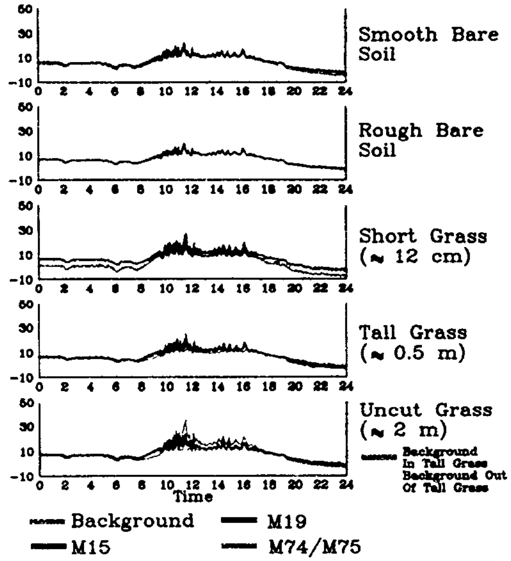


Figure D1. (Sheet 3 of 3)

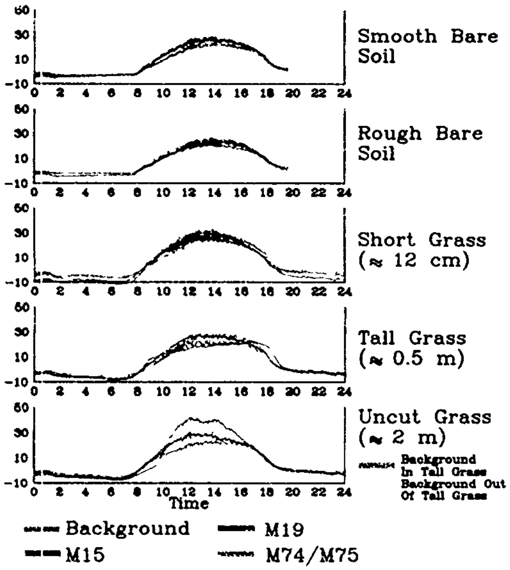
Vicksburg Airport Test
18 OCT



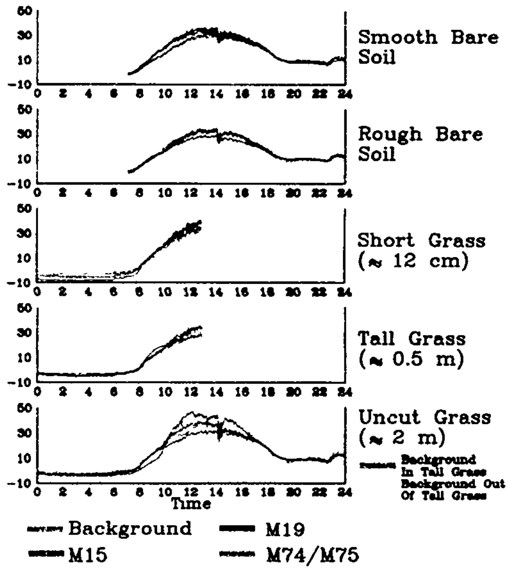
Vicksburg Airport Test
19 OCT



Vicksburg Airport Test
20 OCT



Vicksburg Airport Test
21 OCT



22 OCT 23 OCT

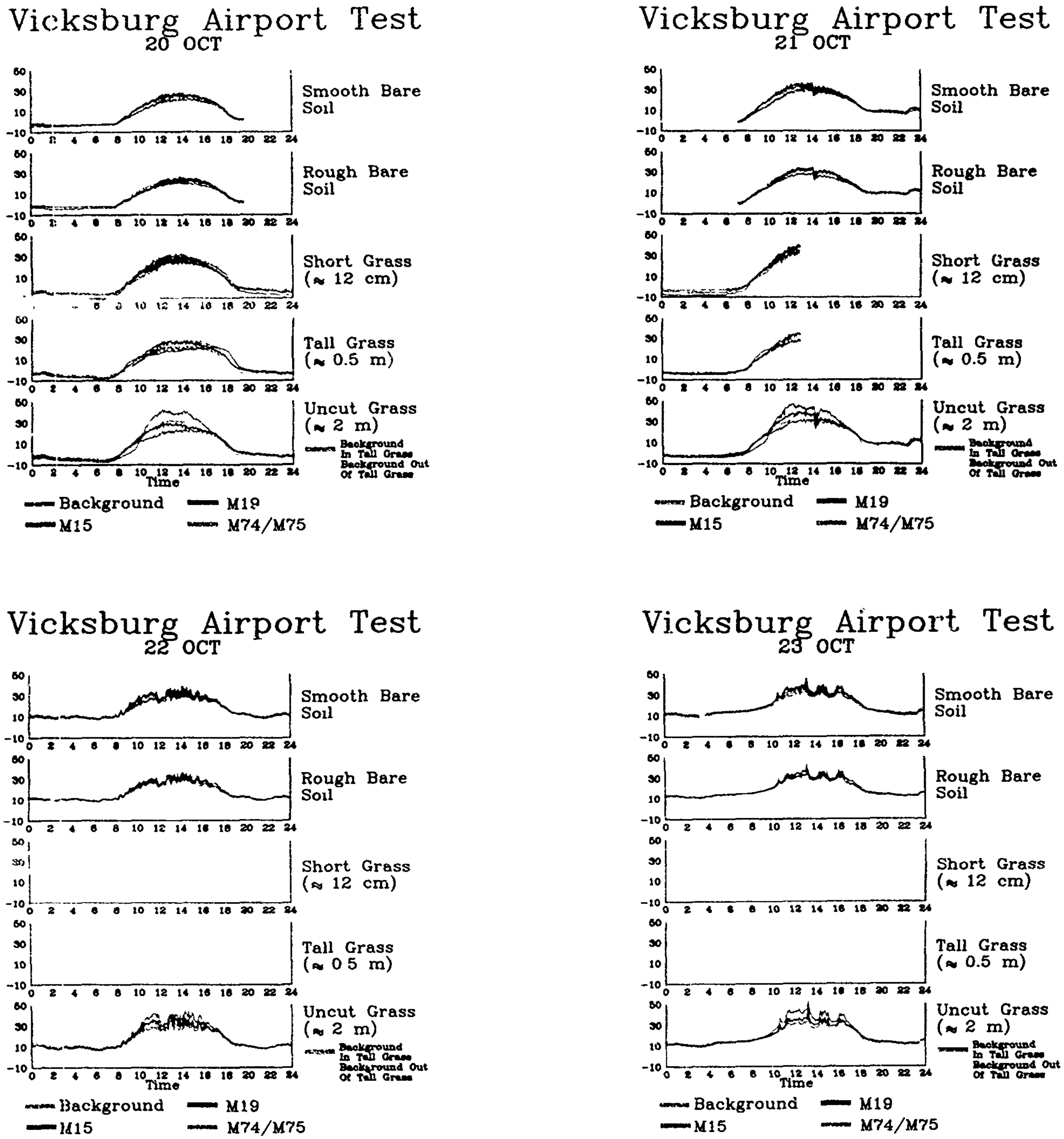
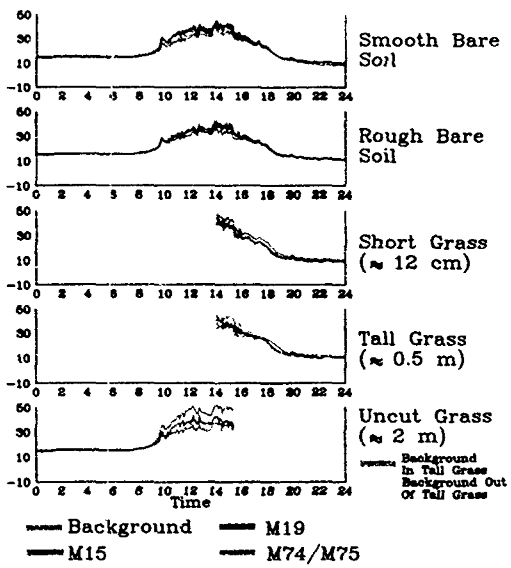
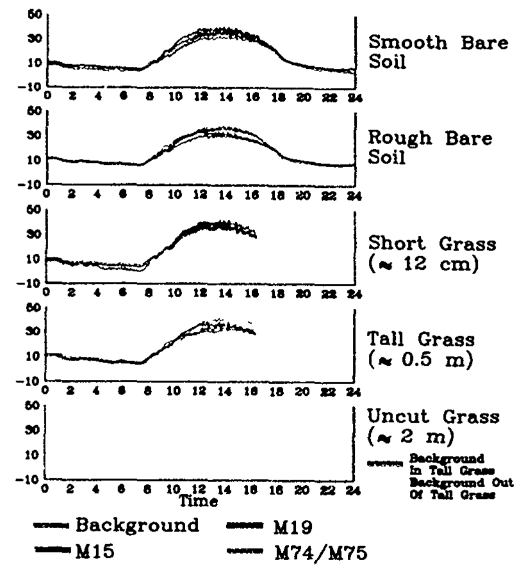


Figure D2. October 1989 thermal records (Sheet 1 of 3)

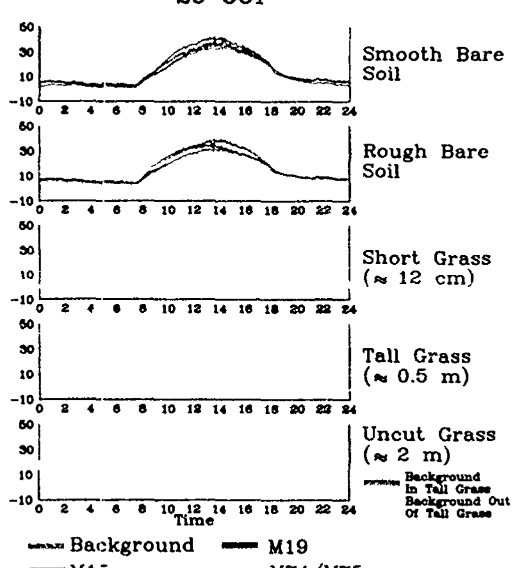
Vicksburg Airport Test 24 OCT



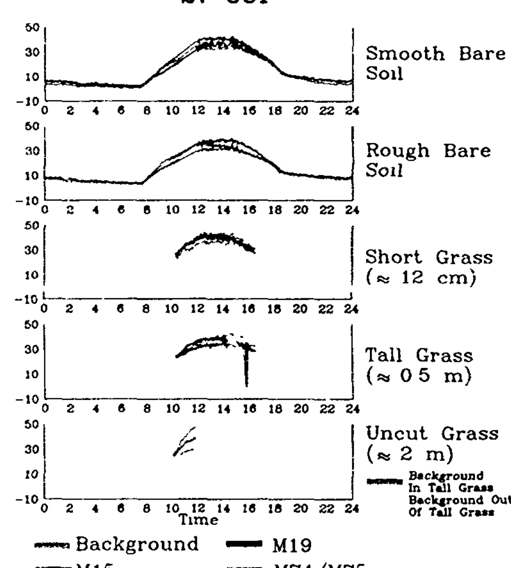
Vicksburg Airport Test 25 OCT

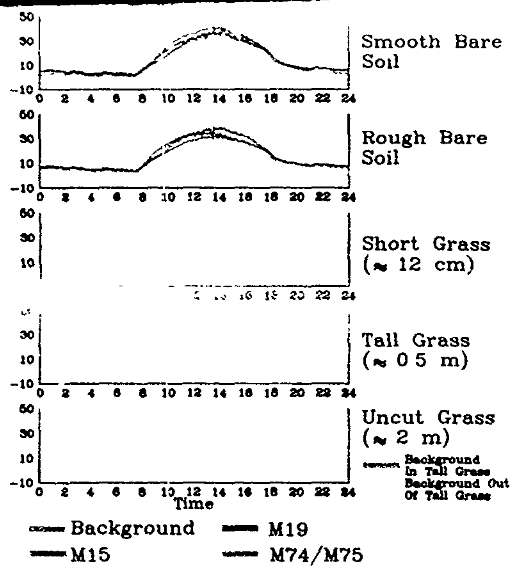


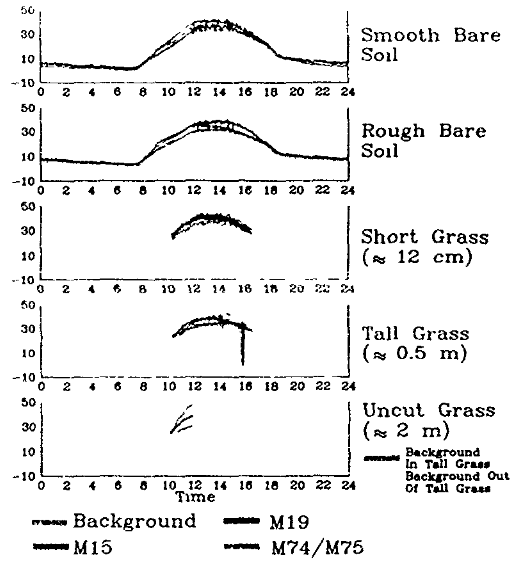
Vicksburg Airport Test 26 OCT



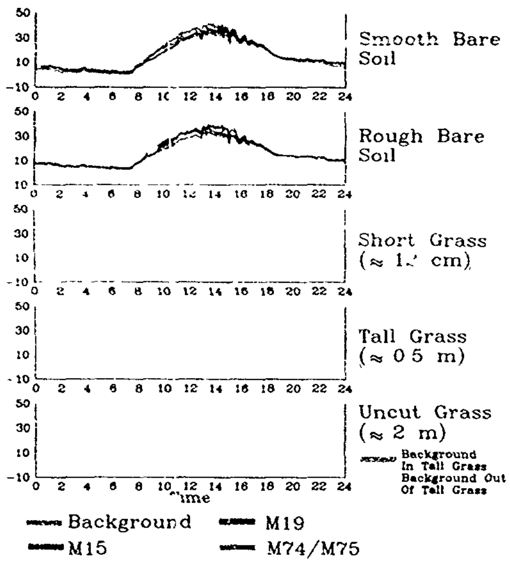
Vicksburg Airport Test 27 OCT







Vicksburg Airport Test
28 OCT



Vicksburg Airport Test
29 OCT

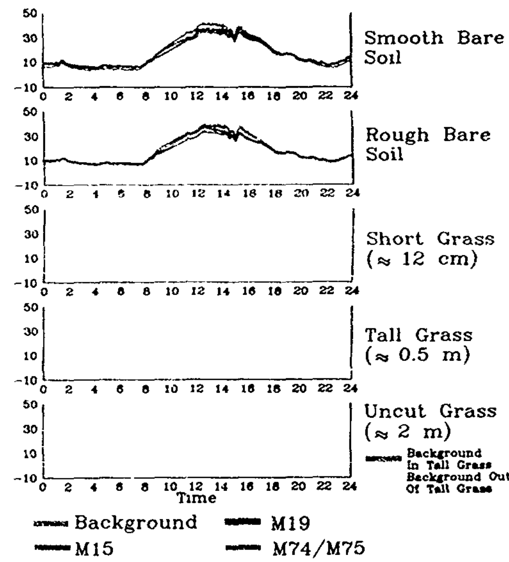
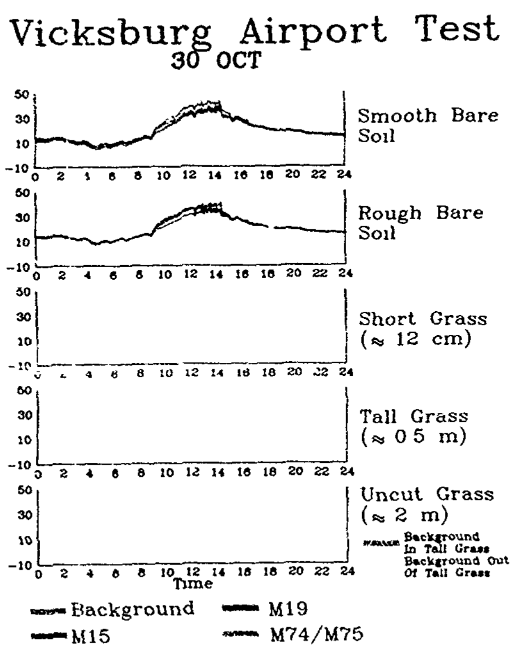
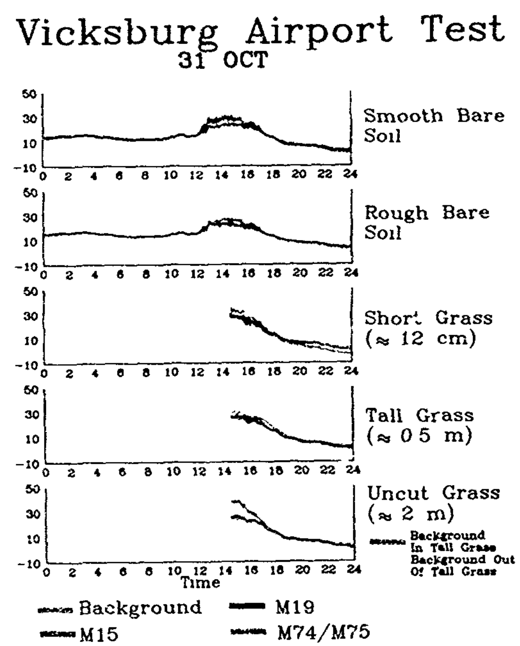
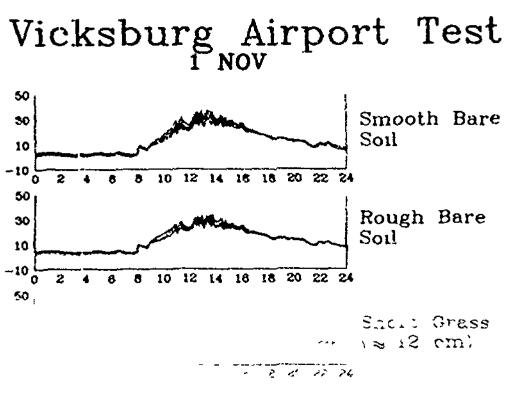


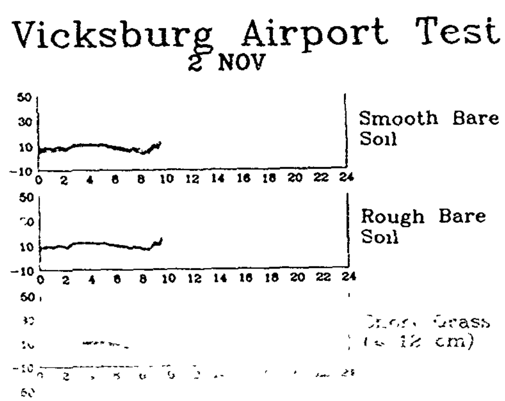
Figure D2. (Sheet 2 of 3)

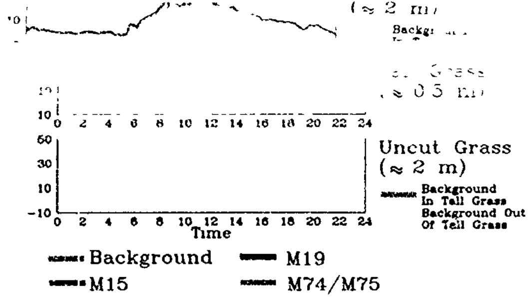
D13-D14

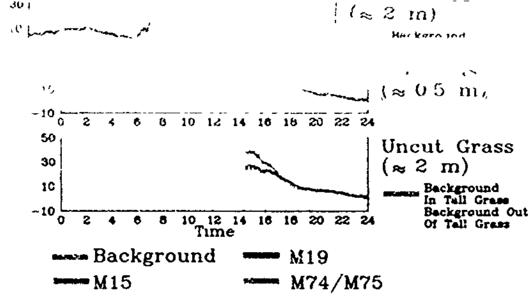

Vicksburg Airport Test
30 OCT
Smooth Bare Soil
Rough Bare Soil
Short Grass (≈ 12 cm)
Tall Grass (≈ 0 5 m)
Uncut Grass (≈ 2 m)
Background In Tall Grass
Background Out Of Tall Grass
Time
Background
M15
M19
M74/M75

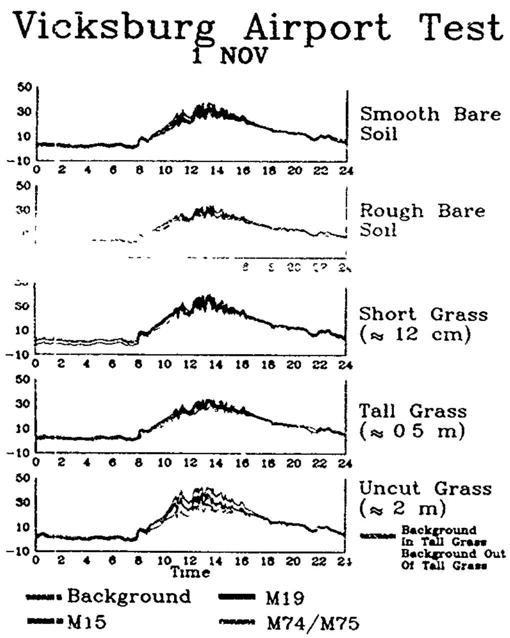

Vicksburg Airport Test
31 OCT
Smooth Bare Soil
Rough Bare Soil
Short Grass (≈ 12 cm)
Tall Grass (≈ 0 5 m)
Uncut Grass (≈ 2 m)
Background In Tall Grass
Background Out Of Tall Grass
Time
Background
M15
M19
M74/M75


Vicksburg Airport Test
1 NOV
Smooth Bare Soil
Rough Bare Soil


Vicksburg Airport Test
2 NOV
Smooth Bare Soil
Rough Bare Soil







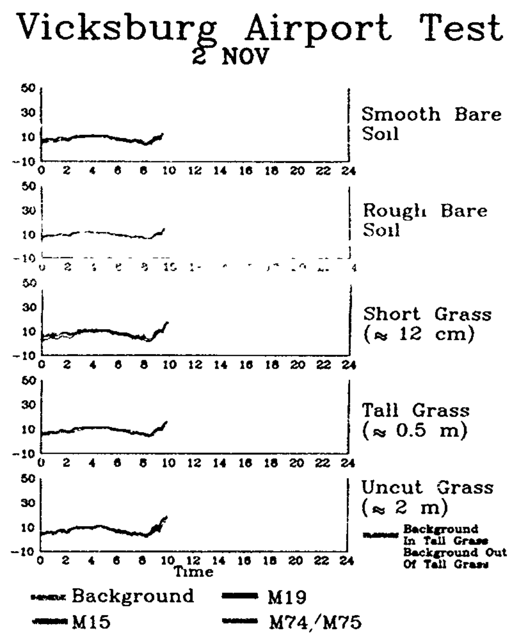


Figure D2. (Sheet 3 of 3)